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International Rice Research Notes

- Bringing hope, improving lives
- A history of rice in Laos

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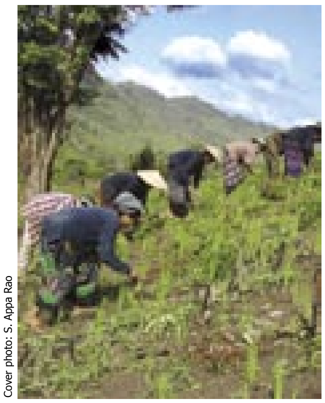

Cover photo: S. Appa Rao

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Bringing hope, improving lives

Robert S. Zeigler, director general, International Rice Research Institute

Rice feeds roughly half the planet's population and approximately three-quarters of a billion of the world's poorest people depend on the staple to survive. A carefully focused agenda for continued research on this vital crop is more imperative than ever. And if all goes as planned, in 2010—while the International Rice Research Institute (IRRI) is celebrating its 50th anniversary—the initiatives spelled out in the Institute's new Strategic Plan (the Plan) will already be starting to have impact.

This Plan, *Bringing hope, improving lives*, is also designed to enable IRRI to do its part in helping partners and nations across the globe to reach the United Nations Millennium Development Goals (MDGs) by 2015.

Certainly, the world has changed enormously since we developed our last strategic plan a decade ago. Recent scientific discoveries—particularly in genetics and genomics—now open up new opportunities to achieve impact that would have been difficult if not impossible as recently as the turn of the century. The reduction of poverty and the sustainability of the rice production environment, through the use of modern technology and the latest communication tools, are at the heart of our exciting and innovative Plan.

Developing the Plan took nearly 12 months. IRRI consulted widely among its partners and stakeholders and sought expert guidance throughout. During these deliberations, we concluded that the MDGs related to hunger, poverty, environmental sustainability, and nutrition and health formed a sound basis and direction for IRRI's future activities. So, we developed five strategic goals and seven research programs to achieve them to reflect this thinking.

Goal 1: Reduce poverty through improved and diversified rice-based systems

Achieving IRRI's first goal—Reduce poverty through improved and diversified rice-based systems—will take the Institute beyond its traditional focus on rice production (increasing productivity or "filling the rice bowl"), which required an emphasis on favorable irrigated areas, to "filling the purse," a major effort to improve farmers' incomes in unfavorable rainfed areas. Nevertheless, rice supplies will need to remain plentiful to provide reliable food that even the poorest can afford. In Southeast Asia, South Asia, and sub-Saharan Africa, rice consumption in 2015 is projected to be, respectively, 13.4 million tons (11%), 22.3 million tons (13%), and 9.5 million tons (51%) above 2005 levels.

This means relatively less research emphasis for IRRI on yield gains for irrigated rice—for which there is now strong capacity among the national agricultural research and extension systems (NARES), particularly in Asia. Instead, IRRI's focus on intensive production systems will shift more to sustainability. In addition, by targeting the MDG on eliminating extreme hunger and poverty as our first strategic goal, we are opening profound new opportunities for IRRI to improve the economic and social well-being of poor rice consumers and farmers.

Program on raising productivity in rainfed environments: attacking the roots of poverty. Rainfed areas coincide to a large extent with regions of severe and extensive poverty where rice is the principal source of staple food, employment, and income for the rural population. Up to now, success has been limited in increasing productivity in rainfed rice ecosystems—home to 80 million farmers on 60 million hectares. Rice yields in these ecosystems remain low at 1.0 to 2.5 tons per hectare and tend to be variable due to erratic monsoons. Poor people in these ecosystems often lack the capacity to acquire food, even at lower prices, because of poor harvests and limited employment opportunities elsewhere.

Our primary objective will be to enhance household food security and income in these rainfed areas of Asia. With rapid advances in genetics and genomics, the chances of developing high-yielding, drought- and flood-tolerant varieties for the rainfed system—and, consequently, helping farmers to diversify their farming systems and thus their income—are much greater now than ever before.

Program on East and Southern Africa: rice for rural incomes and an affordable urban staple. Sub-Saharan Africa is now one of the world's major poverty zones and Goal 1 targets this vast region as well. About 130 million people in East and Southern Africa (ESA) alone live in extreme poverty and more than 85% of these depend on agriculture. A large number of these people are rice consumers and many are small rice producers. A significant investment in agriculture is critical to eradicate hunger and poverty in ESA.

Rural poverty in the ESA region could be significantly reduced if the efficiency of local rice production were improved in the key rice-growing areas of Kenya, Mozambique, Tanzania, and Uganda. Our

research agenda here will also focus on enhancing small farmers' access and linkage to markets. We will collaborate closely with the Africa Rice Center (WARDA), the national programs, and advanced research institutes to capitalize on both the existing knowledge within the countries and the available international expertise.

Goal 2: Ensure that rice production is sustainable and stable, has minimal negative environmental impact, and can cope with climate change

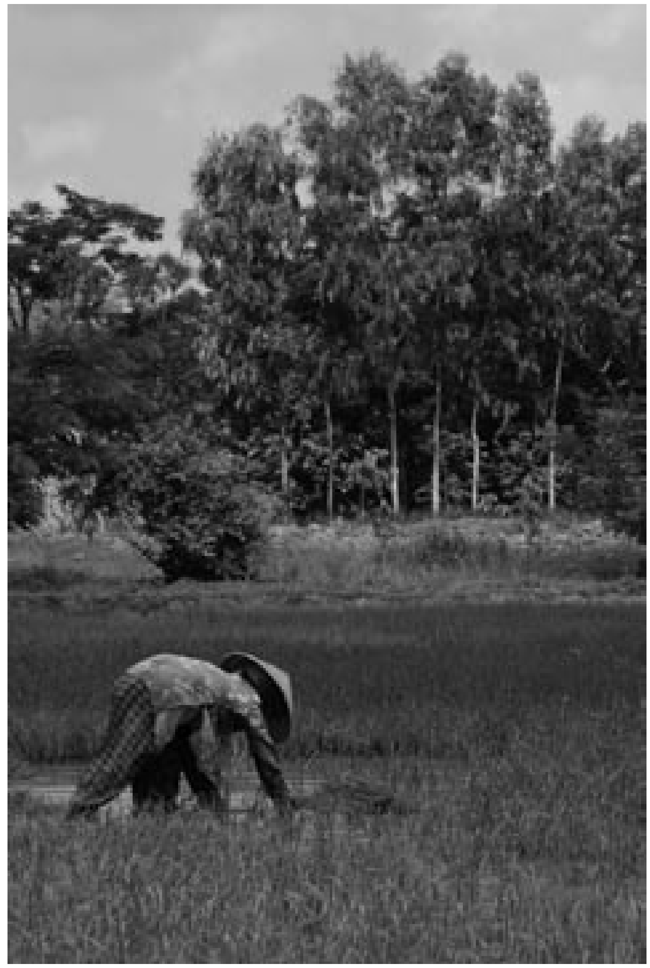
It is critical that the stability and productivity of rice agroecosystems in Asia and Africa not be taken for granted and that their use by future generations not be jeopardized. Rice-growing areas are among the world's most enduring, environmentally sound, and productive agroecosystems, and increased rice production in recent decades has had a significant impact on poverty reduction.

Program on sustaining productivity in intensive rice-based systems: rice and the environment. Rice ecosystems provide basic commodities and regulatory services, including nutrient and water cycling, and biological control to reduce pest and disease outbreaks. Poor people often depend on these "ecosystem services" to provide their needs as they are often without infrastructure to obtain clean water, food, and fuel. Environmental sustainability and ecosystem services are threatened, however, by the loss of biodiversity, climate change, and inappropriate management systems often caused by land, water, or labor shortages.

Strategies are urgently needed to preserve the natural resource base while improving productivity in rice agroecosystems in the face of changing physical and socioeconomic environments. IRRI will focus on land management, biodiversity, water availability and productivity, and the impact of climate change to develop and promote technologies and options to sustain rice-producing environments.

Goal 3: Improve the nutrition and health of poor rice consumers and rice farmers

Nutritional deficiencies, especially in women and children in both Asia and Africa, often go hand in hand with extreme poverty because poverty is a major factor limiting diversity in the diet. Reliance on a single staple, such as polished rice, does not provide the requisite suite of minerals and vitamins necessary for healthy growth and development and



leads to widespread nutritional deficiency in many of the 1.2 billion people in Asia and sub-Saharan Africa living in extreme poverty.

Program on rice and human health: overcoming the consequences of poverty. This program will bring together the multiple rice biofortification projects (including the HarvestPlus Challenge Program) and other health-related efforts that already investigate germplasm, farm practices, and policy options.

Underpinning maximum success in meeting many of the MDGs is the need to solve the widespread problems of health and nutrition that debilitate people and hinder economic growth. Poor nutrition is manifested in invisible nutritional deficiencies (hidden hunger) and in malnutrition (visible hunger). In addition, poor health in the context of rice cultivation may be related to chronic and infectious diseases from water and from vectors such as rodents and mosquitoes, as well as illness attributed to the improper handling of farm chemicals.

For much of the work in this program, the delivery chain includes partners in NARES for the co-development and deployment of germplasm (seeds and the genetic material they contain) and agricultural practices. However, IRRI will greatly expand its interactions with the public health sector in developing countries, for both policy and delivery effectiveness.

This process has already begun in the Golden Rice Network for India and the Philippines and this will serve as a model for other products. The existing structures in the Golden Rice Network and in HarvestPlus have already brought together many of the relevant national and regional institutions needed for impact.

Goal 4: Provide equitable access to information and knowledge on rice and help develop the next generation of rice scientists

Developments that will affect all of the efforts mentioned so far are the rapidly increasing availability and affordability of information and communication technology, such as the Internet, mobile phones, and powerful computers. These new technologies have created important opportunities to allow people with common interests to form communities, communicate, and collaborate.

They have also raised new obligations for IRRI to curate, exchange, and share not only its own body of information, data, and experience but also that of the world's knowledge about rice in all its forms. This will not only enhance global rice research efforts but also empower developing-country rice scientists with state-of-the-art information and knowledge and their associated tools.

Program on information and communication: convening a global rice research community. This effort will build on many global investments in information and technology within and outside IRRI's parent organization, the Consultative Group on International Agricultural Research (CGIAR).

Through this program, we are formally attempting to consolidate all IRRI research and development on information and communication technology for rice science and extension under a single coordinated activity. We plan to place bioinformatics and communication tools directly in the hands of crop scientists, extension agents, and farmers to deliver impact through two major pathways, which will enhance the capacity of IRRI's six other research programs to deliver impact more effectively.

The first pathway is Internet dissemination via a World Rice Community Portal of restructured and cross-linked information on crop science and extension. The second pathway is direct engagement of science and extension communities using current communication technologies, both new, such as Web portals, videoconferencing, and cell phones, and traditional, such as radio and television.

Goal 5: Provide rice scientists and producers with the genetic information and material they need to develop improved technologies and enhance rice production

Another ingredient in the mix that will continue to contribute to the impact of IRRI's research agenda is the rice germplasm it has assembled over nearly half a century. IRRI now maintains, on behalf of humanity, the world's most complete and diverse collection of rice germplasm and this leads to our fifth and final goal.

Program on rice genetic diversity and discovery: meeting the needs of future generations for rice genetic resources. There are still significant gaps in IRRI's germplasm collection and, despite the advanced state of knowledge of the rice genome, information is scant on what diversity of genes exists within the rice gene pool, what these genes do, and how they may help meet the needs of rice producers and users. Meanwhile, genetic erosion in the field continues.

We expect a greater demand for specific genetic resources to address production and environmental problems in the future. This will translate into a greater demand for the genetic knowledge and tools that are needed to identify and use resources that meet specific needs.

Through genomics (the science of discovering genetic structure, variation, and function, and the interrelationships among these), genetic knowledge can now be integrated across species, leading to accelerated discovery of gene functions. Furthermore, genome-wide analysis has the potential to reveal new insights about genetic pathways, and create new opportunities to meet both anticipated and unforeseen challenges.

Bringing together germplasm conservation, diversity analysis, and gene discovery under this single program presents a unique opportunity to maximize the utility of conserved and customized germplasm. This program will offer a comprehensive, well-documented germplasm base, a public research platform to enable gene identification, and genetic knowledge for priority traits. Building on the investments and achievements made in germplasm characterization, functional genomics, and bioinformatics, IRRI is poised to play a major role in gene function discovery, applications of genetic knowledge, and conservation and sharing of genetic resources.

Policy support and impact assessment

One last new program, which will be critical to achieving the five Plan goals, is *Rice policy support and impact assessment for rice research*. The impact of rice research on poverty reduction and environmental sustainability depends on policies and appropriate technologies that address farmers' livelihood needs.

To effectively set research priorities, we must understand the broad trends in socioeconomic and policy environments that affect the economics of rice production. This involves analyzing trends in rice production and consumption at national and subnational levels and shifts in comparative advantages in rice production relative to other crops across regions and ecosystems.

IRRI aims to provide sound advice to policymakers, research managers, and donors regarding research priorities and the design of agricultural interventions through policy analyses, livelihood studies, and impact assessments focused on rice-based systems of Asia.

By making regional comparisons of rice economies and associated livelihoods, the program will help produce a global view of the drivers of change and their impacts. In addition, we will develop research approaches and tools that will have wider application for policy research and impact analysis. We will also closely partner with NARES to help build their capacity for broader socioeconomic and policy analyses of the agricultural sector. NARES, sister CGIAR centers, and advanced research institutes will all have key collaborative roles in the program.

Visionary frontier research

IRRI has a 46-year history of investing in visionary "frontier" research—research that, when successful, has revolutionized agriculture. The original frontier project was none other than the incorporation of semidwarf genes to create the modern high-yielding varieties that began with the release of IR8 40 years ago and spurred the Green Revolution in rice.

Three new Frontier Projects, involving work on drought tolerance, climate change, and producing a more productive and efficient rice plant are intended to accentuate the Institute's commitment to achieving its new goals. They will constitute novel and focused research on problems of strategic importance to future rice production and the environment. The projects will be undertaken by multi-institutional, international research teams, and we expect that significant portions of the research will be conducted at collaborating institutions in both developed and developing countries.

Drought and productivity in unfavorable rice environments (tied to Goal 1). Recent IRRI research has shown that the drought tolerance trait is strongly influenced by genes and gene networks with large effects. This project will scale up their detection, analysis, and delivery for use in marker-aided breeding. By incorporating genes for this trait from rice and other species into widely grown rice varieties, technologies can be developed with national agricultural research systems and provided to farmers to enhance and stabilize their rice yields and income.

Climate change and sustainability (tied to Goal 2). Climate change brings new problems for the sustainability of rice production. Further, changes in air quality and composition, acid rain, and Asian "brown" clouds will produce a new bio-climate for food production systems. Rice cultivation is often viewed as a contributor to climate change through the production of greenhouse gases. Given the essential role of rice in the food system, solutions must be sought that not only minimize the impact of rice production on the environment but also sustain productivity and environmental quality. Strong science will decipher the causes and effects involved, improve germplasm adaptation to expected future climatic conditions, and mitigate the negative effect of agriculture on climate.

A much more productive and efficient rice plant (tied to Goal 5). Plants like maize and sorghum have a more efficient photosynthetic mechanism (called C4) for converting energy to biomass than rice (a so-called C3 plant). C4 plants are also more efficient in nitrogen and water use, and are generally more tolerant of high temperatures. Genomic sciences and comparative biology may be able to break the yield ceiling of rice and enhance its water- and nitrogen-use efficiency by changing the photosynthetic mechanism in rice to that of the more efficient plants. IRRI has formed a C4 rice consortium of senior scientists from both advanced research institutes and developing countries to chart and conduct research to develop a C4 rice plant.

Conclusion

We have identified five strategic goals, have set targets by which our performance can be measured, and have established seven programs to achieve them. While the targets are realistic, they still remain challenging for all of us. The new Plan endeavors to take us over a modest 9 years so that we can contribute significantly to reach the MDGs by 2015. Nevertheless, much of the work outlined here today to bring hope to millions and improve their lives will obviously extend well beyond that date.

So, I believe IRRI's future is certainly something truly to get energized about and that, all-in-all, we are well positioned to move forward aggressively and take advantage of new opportunities and, most importantly, address some very difficult challenges that we only dreamed of hitting not too many years ago. IRRI is truly reinvigorated and is clearly relevant to the MDGs broadly accepted by the global community. I am excited about what IRRI will accomplish over the next years and am sure that you our partners and colleagues will join in and support us.

For more information on IRRI's new Strategic Plan, please go to http://www.irri.org/BringingHope/ImprovingLives.

A history of rice in Laos*

J. M. Schiller, Hatsadong, and K. Doungsila

Most historians trace the origins of the Lao nation-state back to 1353, the date of the coronation of Fa Ngum as the first ruler of the kingdom (mandala) of Lan Xang. The history of rice in what is now known as Laos predates the founding of Lan Xang, however, by thousands of years.

Although the history of the ethnic diversity of what is now known as Laos is generally well documented (Dommen 1995, Simms and Simms 1999, Stuart-Fox 1998), the history of some aspects of rice cultivation within the area is still open to conjecture. What is accepted, however, is that rice has been cultivated in the region for a long time. This is reflected in linguistic evidence where, in the Lao language, as in several other languages in the Asian region, the words for rice and food are synonymous. Anthropological studies in northeast Thailand have provided evidence of rice cultivation from pottery imprints of grain and husks of *Oryza sativa* dated to at least 2,000 BC and probably older (Khush 1997, White 1997). Palaeoenvironmental evidence suggests the presence of even older plant cultivation in the middle Mekong basin (White et al 2004), although the precise crops grown have yet

*This chapter is excerpted from the book *Rice in Laos*, edited by J.M. Schiller, M.B. Chanphengxay, B. Linquist, and S. Appa Rao (see back page for more details).

to be determined. In a review of "the peopling and prehistory of Laos," Stuart-Fox (1998) suggests that rice was cultivated, using broadcasting techniques, along the margins of ponds and streams by small settlements in the area, from the late fourth and early third millennia BC. It is conjectured that, before the deliberate cultivation of rice in the region, harvesting of the grain of its wild rice progenitors probably took place (Harlan 1995, Oka 1988, Vaughan 1994, White 1995).

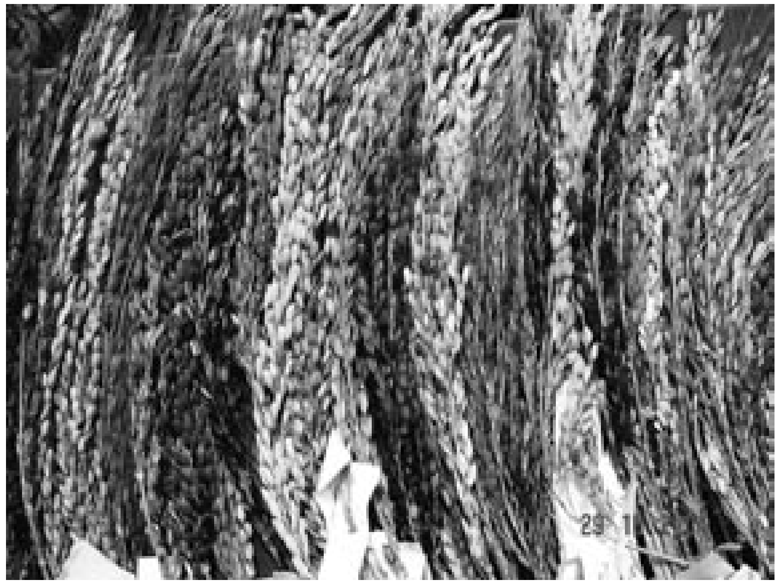
"Wet"-rice cultivation in the lowlands of Laos and neighboring countries has long been associated with ethnic groups connected with the main linguistic group of the region, the Tai. The Tai, in their area of origin in southern China, probably already had a staple diet of wet rice. They built their villages in river valleys where there was plenty of water and level ground that could be flooded in the growing season (Simms and Simms 1999). Golomb (1976) also supports the belief that the Tai were traditionally wet-rice cultivators in their ancestral homeland.

Stuart-Fox (1998) and Higham (2002) indicate that, as early as 500 BC, the local population in what is now known as the Khorat Plateau of northeast Thailand was using domesticated buffalo and iron-tipped plows for wet-rice cultivation. He suggests that, despite a lack of systematic evidence to date, similar agricultural developments likely occurred on the plains of the Lao provinces of Vientiane, Khammouane, and Savannakhet. When the Tai people moved into what now constitutes Laos, Thailand, and upper Myanmar, they brought with them their own wet-rice cultivation practices.

The Tai-Lao currently form the dominant linguistic group in several provinces of Laos, including Vientiane, Luang Prabang, Khammouane, Savannakhet, and Champassak (Batson 1991). Other Tai groups that live in Laos are the Tai-Leu of Luang Prabang and areas to the north, the Tai-Neua of Houaphanh, and the Tai-Dam (Black Tai) and Tai-Deng (Red Tai) of Phongsaly and Houaphanh. Of the Austroasiatic groups who live in the adjoining uplands, the Kasseng, Loven, Souay, and Bru are the larger groups inhabiting southern Laos, while the Lamet and Khmou are the major groups in the north. The largest single grouping of the Mon-Khmer comprises the Khmou, now concentrated in parts of Luang Prabang, Houaphanh, and Oudomxay provinces. The existence of canals and reservoirs in the southern Lao province of Champassak suggests that lowland irrigated rice cultivation was the principal sustenance crop in southern Laos during the period of Khmer dominance from the 5th to 11th centuries CE.

It is therefore reasonable to assume that, for the last two millennia, the main form of rice cultivation in what is now Laos was wet-rice cultivation in the lowlands. Just when dryland rice cultivation, which is found in the upland environment of Laos and neighboring countries, developed is a matter of conjecture. Khush (1997) suggests that early rice crops in the Asian arc were "probably grown by direct seeding and without standing water." Harlan (1995) also infers that, at least in the areas of original domestication of rice in Asia, wet-rice cultivation is a relatively more recent production method than dryland cultivation techniques. However, White (1995) argues on ecological grounds that dryland rice cultivation must have emerged from initial domestication in a wetland environment. The process of soil puddling and transplanting of seedlings seems to have originated in China and been brought to Southeast Asia (including Laos) through migration. It should be noted, however, that the last ethnic groups to arrive in Laos, the Hmong and Mien

(Yao), who settled in the highlands of Laos in the 19th and early 20th centuries, brought with them dryland rice cultivation practices (Dommen 1995).



Laos and the origins of cultivated Asiatic rice

Though rice cultivation in Laos may date back only to the second millennium BCE, it should be acknowledged that Laos lies within the broader region of likely domestication of Asiatic rice (*Oryza sativa*) (Chang 1976, Oka 1988). Laos is also believed to be near the center of origin of glutinous rice (Golomb 1976, Watabe 1967). Laos is still rich in genetic diversity of wild and weedy rice, with 6 of the known 21 species of wild rice still to be found in the country: *O. rufipogon*, *O. nivara*, *O. minuta*, *O. officinalis*, *O. ridleyi*, and *O. granulata* (Kuroda et al. Two of these, *O. nivara* and *O. rufipogon*, are the generally accepted progenitors of Asian rice, *O. sativa* (Chang 1976, Oka 1988, Yamanaka et al 2003). Weedy rice, believed to be the interspecific hybrids between the cultivated rice species (*O. sativa*) and wild rice species, has also been commonly observed in Laos.

Historical evidence for the quality of Lao rice

Reference to the quality of rice produced in Laos comes from historical records from the early 1660s, when the description of Laos by an Italian Jesuit priest who worked in the country between 1642 and 1648 was published. The account by Father Givvani Maria Leria was first published in Italian in 1663 (de Marini 1998). The description of rice (and other matters of interest) on both banks of the Mekong River runs as follows:

"However, one must understand that this part of the kingdom, west of the river, is not as prosperous or as fertile as that in the east which greatly surpasses in all respects. The elephants are bigger and stronger there, better trained and more suitable for warfare. The unicorns (rhinoceroses) are also better there than elsewhere. The staple rice is incomparable there and it has a characteristic odour and wildness that is specific to all that grows in this eastern part of the kingdom. There, forests and trees are high, straight and almost all durable, a quality which those growing on the eastern side of this river do not possess: there the virtue of the unicorns is not at all comparable to that of the eastern side. The rice is so hard that one could never boil it and the wood, badly shaped and twisted—it is more suitable for making smoke than fire. There is a kind of a small strait—it is like the center and middle of the kingdom—which produced such excellent rice that I do not believe that it has its equal anywhere else in the Orient" (de Marini 1998, p 4-5).

Ngaosyvanthn and Ngaosyvanthn (1998) also cite other sources from the 18th century saying that "this country produces abundantly the best kind of rice." Reference is also made to the royal paddy fields established by the last king of Vientiane, Chao Anouvong (1804-28), within an 18-km wall encircling the city. The occupying Thai armies of 1827 were reportedly surprised at how well endowed Vientiane was with rice. The royal rice fields were apparently still discernible more than 60 years later.

Rice-based power

Following the settlement of the Tai-Lao in the lowland areas in what now comprises Laos, and northeast Thailand, there evolved a number of small political centers known as muang, which were concentrations of social, economic, and military power. Stuart- Fox (1998) reports that the earliest of these Tai muang "of more than local extent" on the upper Mekong "probably dates from no earlier than the 11th century." These muang were generally centered in valley areas from where they controlled surrounding territory. Control over areas of reliable food production provided the basis of muang power for hundreds of years. The four oldest and strongest muang in what constitutes modern-day Laos were centered on what are currently the provinces of Luang Prabang, Xieng Khouang, Vientiane, and

season lowland rice and other crops grown in areas adjacent to the Mekong River and its tributaries. Production for most of this period did not exceed 350,000 t annually (equal to about 1 kg of rice per day per person for the population of that time) (Gunn 1990). An exception was in 1923 when production was reported to have reached a high of 500,000 t. Gunn (1990) reports that, for most of the period of French colonialism, Laos was a net rice-importing country, with only the Champassak area consistently producing a rice surplus. One of the few interventions by the French to address the chronic rice deficit during the time of their administration of Laos was to actually ban the export of rice in 1936 (Gunn 1990, Stuart-Fox 1997). This was in response to a drop in the estimated harvest from about 258,000 t in 1935 to about 204,000 t in 1936 (the cause of this reduction is not indicated but, as it was mainly from the traditional rice-exporting provinces adjacent to the Mekong River, it is likely to have been severe flooding). The rice deficit was of such a magnitude in Thakek Province (Khammouane) that there was a fear of starvation. At the time, emergency supplies of rice were requested by the Résident Supérieur from Tonkin and Annam (Gunn 1990).

Champassak. All exercised domination over rice-growing areas that produced significant surpluses (Whitmore 1970).

The decision, in 1560, of King Xetthathirât of Lan Xang to move the royal court from Luang Prabang (or Xieng Thong as it was called at that time) to Vientiane was partly based on the growing food needs (mainly rice) of the administrative center. As well as being at the crossroads for much overland commerce, compared with Luang Prabang, Vientiane lay in a much larger rich and fertile plain well suited to wet-rice cultivation (Simms and Simms 1999).

The significance of rice politically was demonstrated during the rule of Chao Anou, King of Vientiane (1805-28), who led the Lao war of independence against Siam (Thailand) in 1827-28. After Chao Anou's initial defeat, he returned to Vientiane, where he found a Siamese garrison in control of the only available rice supplies. Conflict again broke out between the Siamese and the Lao, leading to Chao Anou's capture and death, and the final destruction of Vientiane (Stuart-Fox 1998).

Rice and French colonialism

During the period of French colonialism in Laos (1893-1945), although coffee and potato growing were introduced to the Boloven Plateau in the south of the country, little effort was made to improve production of the staple crops of rice and maize (McCoy 1970). Almost 100% of the rice produced was grown under rainfed conditions and thereby subject to the vagaries of the weather, with periodic droughts affecting both upland and lowland crops, and periodic flooding occasionally devastating wet-

USAID

The period 1955 to 1963 was a time when the per capita U.S. assistance to Laos exceeded, several fold, that given to other countries in the region. However, very little was spent on agriculture, although more than 90% of the population at that time was farmers (Stuart-Fox 1997). During the 1960s and early 1970s, agricultural development and efforts to achieve rice self-sufficiency were of minor importance in comparison to the escalating military conflict. In 1969 and 1970, USAID did undertake the evaluation of a number of introduced lines and varieties from IRRI, together with some well-known traditional varieties. The lines and varieties from IRRI would have been some of the earliest available, as the institution was established only in 1960. Early multilocation yield trials were undertaken in the provinces of Sayabouly, Khammouane, Luang Prabang, Vientiane, and Sedone (Sedone Province was later incorporated into the province of Champassak). Seed multiplication of several of these IRRI lines and varieties was undertaken for distribution at the Salakham Rice Research Station near the capital, Vientiane, in the 1973 wet season. In addition to the IRRI material (which included both glutinous and nonglutinous lines, the latter including IR22 and IR24), the Lao traditional glutinous variety Do nang nouan and the Thai glutinous variety Sanpatong were also multiplied and distributed to farmers. Some of these varieties were still being grown on a limited scale in the mid-1990s, being known as American rice, reflecting their origins as part of the USAID seed distribution program (Appa Rao et al 2000). Apart from the limited work on the introduction and distribution of rice varieties, little other agricultural development took place during this period because of the displacement of large parts of the population in many areas by the war, and the associated disruption of normal cropping cycles.

Socialist assistance 1977-90

Vietnam

In support of the agricultural cooperatives that were established from 1978 to 1984 in an attempt to improve agricultural productivity, Vietnamese agricultural advisers introduced and evaluated many improved lowland rice varieties from Vietnam. Most of these introductions were nonglutinous and many had IRRI parentage. However, few of the Vietnamese introductions were actually adopted by Lao farmers because of their poorer eating qualities relative to the traditional Lao varieties. One of the Vietnamese introductions, CR203, did become popular for the production of rice noodles and brewing of Lao beer. In 2002, it was still being grown on a limited scale.

USSR

Although large numbers of advisers from the socialist block countries (particularly Russia) were present in Laos during the late 1970s and 1980s, these advisers and related assistance programs had little influence on agricultural production. The advisers did undertake serious soil surveys and soil-mapping exercises during this time, the results of which were later used for the production of more standardized USDA-type soil maps that, in turn, were used for land-use planning purposes in the late 1990s. In 1982-84, in collaboration with USSR experts, a number of field trials were undertaken on rice, focusing on yield responses to fertilizer inputs. These studies were part of the soil classification mapping exercises.

The rise and fall of agricultural cooperatives: 1978-88

The most significant change relating to rice production in the period immediately after the Lao People's Revolutionary Party (LPRP) came to power in December 1975 was the adoption of a policy for the "collectivization of agricultural production" through the formation of "agricultural cooperatives." This was seen as the most appropriate strategy for "revolutionizing the country, both socially and technologically." The history of the "rise and fall" of these cooperatives has been reviewed in detail by Stuart-Fox (1980) and Evans (1988, 1995). As reported by Evans, the "experiment with collectivization was associated with attempts by the new government to revive the Lao economy following its collapse due to the flight of both capital and business entrepreneurs." It was hoped to use agricultural

cooperatives as the basis for quickly increasing rice production to alleviate a serious and chronic rice deficit in the country. At the time, Laos was importing approximately 15% of its rice requirements. It was believed that cooperatives were the only way peasant agriculture could overcome natural calamities and achieve national food self-sufficiency (Evans 1995). To support these objectives, controls were placed on the price of a range of agricultural commodities, including rice.

Although the policy to create production-based collectives was announced soon after the change of government in 1975, it was not implemented until 1978, following a severe drought in 1977 that further aggravated the already serious rice deficit in the country. The focus of the move to cooperative-based production was in areas of lowland rice cultivation (mainly rainfed, as there was only a very small area of irrigated rice at the time the cooperatives were formed) in provinces with large lowland rice-growing areas in the Mekong River Valley, and in some northern provinces where the LPRP had a strong political base (particularly the provinces of Xieng Khouang, Houaphanh, and Phongsaly). A characteristic of the cooperatives was that they were generally small "village-level" initiatives involving an average of 30 to 40 families, rather than large area collectives. Although a few numbered over 200 families, generally such large cooperatives were not encouraged. The initial basis for the formation and operation of the early cooperatives was at a low level, involving the establishment of labor exchange units that could be used in a coordinated calendar of rice production. Members of the cooperative were expected to contribute their cultivated land for the cooperative's use (while property of other types remained under the control of individual households) (Evans 1988). From the outset, it was official government policy that the decision to join or leave a cooperative was to be left to the individual households. In practice, however, coercion was often used to encourage people to join a cooperative, and even more so to discourage a household from withdrawing. In late 1978, Stuart-Fox (1980) reported that 1,600 cooperatives had been set up throughout the country, involving 16% of all farming families. The majority were in the provinces of Khammouane and Champassak, in the central and southern parts of the Mekong River Valley. By early 1979, more than 2,500 cooperatives were reported to have been established. However, by mid-1979, it was recognized that the move to collectivization was seriously disrupting production rather than improving it. The disruptive effects on rice production of a severe drought in 1977, followed by a severe flood in 1978, which devastated rice crops in the main rice-growing areas of central and southern Laos, also affected the move to cooperative production. A lack of management skills on the part of officials responsible for the cooperatives was a further major obstacle to both their establishment and operation. In July 1979, a stop was put to the further expansion of the cooperative program, as there was little support for cooperative-based rice production in most rural areas (Stuart-Fox 1980).

Even so, the government restated its commitment to collectivization of production, by emphasizing strengthening existing cooperatives rather than creating new ones. Because of a general lack of enthusiasm and support in many rural areas, from 1979 to 1980 the number of cooperatives dropped by 45% (from about 2,450 to about 1,340) (Table 1). However, official policy still favored the cooperative

Table 1. Expansion of agricultural cooperatives in Laos, 1979-86.

Province	Year							
	1979	1980	1981	1982	1983	1984	1985	1986
Phongsaly	73	152	152	156	167	167	167	167
Luang Namtha	59	74	74	74	74	74	74	69
Oudomxay	72	93	93	98	98	111	115	182
Sayabouly	120	44	44	89	129	160	160	154
Luang Prabang	41	44	44	76	82	98	101	152
Xieng Khouang	200	212	212	252	251	251	247	247
Houaphanh	155	263	263	274	311	311	318	374
Vientiane[a] Municipality	–	–	–	63	104	119	167	192
Vientiane	486	101	101	47	71	93	176	242
Khammouane	433	12	12	24	67	99	104	372
Savannakhet	250	12	12	18	53	164	547	579
Saravane	235	18	18	168	107	216	254	314
Champassak	304	306	306	587	587	597	651	659
Attapeu	24	12	12	12	13	19	19	14
Bokeo[a]	–	–	–	–	–	40	40	67
Borikhamxay[a]	–	–	–	–	–	17	34	76
Sekong[a]	–	–	–	–	–	10	10	120
Total	2,452	1,343	1,352	1,943	2,114	2,546	3,184	3,976

[a]–indicates that the administrative area did not exist at the time statistics were recorded. Sources: Evans (1988, 1995).

approach to production and in 1982 some attempt was made to extend cooperative-based rice production to areas of "swidden farming." Tax incentives and preferential terms for access to credit were offered as inducements to encourage rural households to join the cooperative movement. It was reported that, by mid-1984, 37.6% of the farm families and 35.3% of the farming land were involved in 2,402 cooperatives nationwide. The cooperative movement was recorded as having reached its peak in 1986, with almost 4,000 cooperatives being reported as having been established (Table 1). However, several authors (Zasloff 1991, Evans 1995, Stuart-Fox 1997) have indicated that most of these cooperatives existed "in name only," and that in reality there were very few genuine working cooperatives. In fact, the cooperative movement was steadily weakened as members became disillusioned and used their "right to withdraw." The provinces where the cooperative movement was most successful were Champassak, Savannakhet, Xieng Khouang, Saravane, and Sayabouly (Evans 1988). By mid-1988, the government officially recognized the lack of success of the "cooperative concept" under Lao conditions and a decision was made to formally abandon the movement as the basis for improving production. It was acknowledged that the family or individual household unit was a more appropriate basis for achieving both political stability and improved agricultural production, particularly of rice. At about the same time, a number of state farms, which were also established as part of the cooperative movement but that occupied no more than 0.2% of cultivated land, were also privatized, as they were absorbing a disproportionate component of public and other resources (World Bank 1995).

Independent of the cooperative movement (but also influencing it), a significant change in government policy that influenced rice production in the early 1980s was the increased flexibility of pricing and market exchange in the agricultural sector (Evans 1991). In 1980, the prices of most crops and export products were raised by 300% to 500%; retail prices of commodities marketed by the state went up by 200% to 300% and approached parallel market prices. One immediate consequence of these increased incentives was a 16.5% increase in rice production. However, it has also been surmised that some of the production increase reported about this time resulted from changes in tax policy. In 1979, the government replaced the rice output tax with a land tax. One result of this was to remove the incentive to underreport yields and production (though this was replaced by an incentive to underreport the area under cultivation, the basis of the land tax). Although in the early years of the cooperative movement the land of those wishing to withdraw was expropriated, this policy was halted in 1979 and land was returned to those households that had opted to leave the cooperatives. As no general program of land reform had been associated with the cooperative movement, the reversion back to the family unit as the basis of production was not difficult.

Development of irrigated rice production

Farmers throughout Laos have been building traditional weirs and canals for centuries to provide supplementary irrigation to their wet-season rice crops. A typical traditional scheme would include a weir made of logs, stones, and sometimes bamboo and earth, with small hand-dug canals. The command area of these traditional irrigation schemes has varied from a few hectares to about 100 ha, governed mostly by the limited areas of flat land within the mountainous watersheds. These small diversion schemes irrigate terraced or valley-floor paddy fields. As of 2002, thousands of these small weir and canal systems were still in operation in Laos.

Although traditional schemes mainly focus on wet-season rice production, some also produce limited dry-season crops in areas where the streams have a significant dry-season flow, and where farmers have seen the potential for producing additional crops. However, on account of low efficiency levels and high labor demand for frequent repairs of the traditional weirs, over the past 20 years, hundreds of traditional systems have been replaced by more permanent structures.

Irrigation schemes

As recently as 1976, shortly after the LPRP came to power within the country, less than 1% (2,700 ha) of the planted rice area, and less than 1% of rice production (about 3,000 t), was associated with dry-season irrigated cultivation (Table 2). The relatively small irrigated area that existed prior to 1975 was mainly in the form of small weir schemes developed by USAID in the north of the country, particularly in the 1960s.

The first relatively large scheme, about 900 ha in area, also initiated by USAID, was the Faay Namtane scheme in Phiang District of Xayabouly Province. In 1977-78, the expansion of irrigated rice cultivation became one of the agricultural development objectives of the socialist government in its bid to achieve food self-sufficiency (basically rice self-sufficiency), and to reduce the year-to-year vagaries in food production caused by the effects of the weather. This development initiative was closely linked to the policy to develop a national network of agricultural cooperatives as the basis for achieving improvements in agricultural production (Evans 1991).

The first large irrigation schemes to be developed in Laos began in the late 1970s and were located on the floodplains of the Mekong River, not far from the capital, Vientiane. The first of these schemes, the Nam Houm scheme, was implemented through the Ministry of Agriculture and Forestry in Nasaythong District of Vientiane Municipality. This reservoir-based scheme, whose development commenced in 1977, had a projected capacity of about 3,000 ha of dry-season irrigated crop production. In its development phase, the Mekong Committee provided some financial assistance for the purchase and installation of pumping equipment for the scheme. The second scheme, also initiated in Nasaythong District of Vientiane Municipality, was the Nam Soang scheme. With a projected dry-season irrigation capacity of 4,000 ha, the development of this scheme began in 1978 through the Ministry of Defense. Despite the construction of reservoirs, a lack of funds to complete the network of delivery canals resulted in failure to meet the planned irrigation potential of both these schemes, and they did little to improve productivity at the time of their development (World Bank 1995). A lack of appropriate management and technical skills also contributed to the inability to properly develop and use these two schemes.

In the early 1990s, a decision was made to expand the area of rice under irrigated production in order to accelerate improvements in rice production to achieve the joint goals of national rice self-sufficiency and greater production stability. The expanded irrigated production was to focus on developing irrigation schemes that could be used for dry-season cropping activities rather than for wet-season production. However, it was also recognized that the proposed schemes had the potential for wet-season supplementary irrigation use as well. From 1990 to 2001, the dry-season irrigated capacity increased by 750% (from 12,000 to 102,000 ha). Production from the dryseason irrigated environment during this time also increased more than tenfold, from 41,000 to 436,000 t (Table 2).

Most (94.5%) of the expansion in irrigated area took place in the central (70,816 ha) and southern (25,578 ha) agricultural regions. In 2001, still only about 5,600 ha were developed for irrigation in the northern agricultural region. Most of this expansion in irrigated capacity during the 1990s depended on pumping water directly from the Mekong River and, to a lesser extent, from tributaries of the Mekong. There was less investment in the development of appropriate water reticulation systems. However, by 2001, the capacity of these recently developed schemes was being underused because of a combination of factors. Farmer groups were increasingly unable and unwilling to meet the increasing fuel costs of diesel pumps (both diesel and electric pump programs had been installed). This was aggravated by the fact that crop yields were well below the expected potential because of low levels of inputs, particularly fertilizer. In some areas, farmers also encountered difficulties in marketing the second rice crop (the dry-season irrigated crop). Water-use efficiency in many scheme areas was also well below the potential because of a lack of concurrent investment in networks of water distribution canals. Further, farmer organizations, to which responsibility for the pumping schemes was being transferred, did not possess the required skills and resources to maintain the systems. By 2002, it also started to be

Table 2. Development of irrigated rice cultivation, 1976-2002.

	Year/area (000 ha)(% total)				Production (000 t)(% total)			
	Rainfed lowland	Rainfed upland	Irrigated lowland[a]	Total	Rainfed lowland	Rainfed upland	Irrigated lowland[a]	Total
1976	317.7	204.1	2.7	524.5	455	202	3	660
(%)	(60.6)	(38.9)	(0.5)	(100.0)	(68.9)	(30.6)	(0.5)	(100.0)
1978	398.6	216.6	7.5	622.7	508	217	9	734
(%)	(64.0)	(34.8)	(1.2)	(100.0)	(69.2)	(29.6)	(1.2)	(100.0)
1980	426.9	297.4	7.7	732.0	705	337	11	1,053
(%)	(58.3)	(40.6)	(1.1)	(100.0)	(67.0)	(32.0)	(1.1)	(100.0)
1982	435.2	296.2	5.7	737.1	731	349	12	1,092
(%)	(59.0)	(40.2)	(0.8)	(100.0)	(66.9)	(32.0)	(1.1)	(100.0)
1984	360.3	256.2	8.6	625.1	919	380	21	1,320
(%)	(57.6)	(41.0)	(1.4)	(100.0)	(69.6)	(28.8)	(1.6)	(100.0)
1986	385.0	256.6	10.1	651.7	1,082	341	27	1,450
(%)	(59.1)	(39.4)	(1.6)	(100.0)	(74.7)	(23.5)	(1.9)	(100.0)
1988	331.3	213.5	11.4	556.2	686	283	35	1,004
(%)	(59.6)	(38.4)	(2.1)	(100.0)	(68.3)	(28.2)	(3.5)	(100.0)
1990	392.4	245.9	12.0	650.3	1,081	369	41	1,491
(%)	(60.3)	(37.8)	(1.9)	(100.0)	(72.5)	(24.8)	(2.8)	(100.0)
1991	322.8	234.1	13.3	570.2	842	337	44	1,223
(%)	(56.6)	(41.1)	(2.3)	(100.0)	(68.9)	(27.6)	(3.6)	(100.0)
1992	392.5	200.1	15.5	608.1	1,153	292	55	1,500
(%)	(64.6)	(32.9)	(2.5)	(100.0)	(76.9)	(19.5)	(3.7)	(100.0)
1993	350.4	188.3	13.0	551.7	921	284	46	1,251
(%)	(63.5)	(34.1)	(2.7)	(100.0)	(73.6)	(22.7)	(3.7)	(100.0)
1994	380.9	219.1	11.0	611.0	1,198	342	38	1,578
(%)	(62.3)	(35.9)	(1.8)	(100.0)	(75.9)	(21.7)	(2.4)	(100.0)
1995	367.3	179.0	13.6	559.9	1,071	296	50	1,417
(%)	(65.6)	(32.0)	(2.4)	(100.0)	(75.6)	(20.9)	(3.5)	(100.0)
1996	363.1	172.6	18.0	553.7	1,076	266	72	1,414
(%)	(65.6)	(31.2)	(3.3)	(100.0)	(76.1)	(18.8)	(5.1)	(100.0)
1997	421.1	153.6	26.6	601.3	1,300	247	114	1,661
(%)	(70.0)	(25.5)	(4.4)	(100.0)	(78.3)	(14.9)	(6.9)	(100.0)
1998	430.2	134.2	53.1	617.5	1,249	214	212	1,675
(%)	(69.7)	(21.7)	(8.6)	(100.0)	(74.6)	(12.8)	(12.7)	(100.0)
1999	477.2	153.4	87.0	717.6	1,502	247	354	2,103
(%)	(66.5)	(21.4)	(12.1)	(100.0)	(71.4)	(11.8)	(16.8)	(100.0)
2000	475.5	152.1	91.8	719.4	1,553	259	390	2,202
(%)	(66.1)	(21.1)	(12.8)	(100.0)	(70.5)	(11.8)	(17.7)	(100.0)
2001	486.8	158.1	102.0	746.9	1,620	279	436	2,335
(%)	(65.2)	(21.2)	(13.7)	(100.0)	(69.4)	(12.0)	(18.7)	(100.0)
2002	519.5	134.6	84.0	738.1	1,801	240	375	2,416
(%)	(70.4)	(18.2)	(11.4)	(100.0)	(74.6)	(10.0)	(15.5)	(100.0)

[a]Statistics represent dry-seas¤
(May-October). Sources: World Bank (1995), Ministry of Agriculture and Forestry, Vientiane, Lao PDR.

recognized that the dry-season irrigation potential might be better used for crops with higher returns than rice. The 2002-03 dry season therefore saw a significant reduction in the use of the potential of many of the schemes developed during the 1990s.

In 2000, it was estimated that Laos had 22,240 irrigation systems, with a capacity to serve about 280,000 ha in the wet season, or about 36% of the country's 800,000 ha of annually cultivated land. Irrigated land accounted for about 65% of total agricultural production. The majority of the schemes were traditional weirs, some 18,150 in total, located mostly in mountainous areas, and accounting for about 35% of the total irrigated area.

Since 1975, various agencies have been involved in programs of assistance to improve irrigation capacity within Laos. These agencies are the European Community, United Nations Development Programme (UNDP), United Nations Capital Development Project (UNCDP), Mekong River Commission, Organization of Petroleum Exporting Countries (OPEC), the World Bank, the national assistance agencies of Australia and Sweden, and many NGOs.

The impact of natural disasters on rice production

Lao agriculture generally and rice production in particular have always been at the mercy of the weather, bad years being fatalistically accepted along with the good ones. With rice production accounting for more than 80% of the cultivated land area and rice consumption accounting for more than 80% of the calorie intake in many rural areas, the impact of adverse climatic conditions on the livelihood of the Lao people has always been potentially threatening. The occurrence and level of poverty in many areas are recognized as being largely determined by the level and frequency of natural disasters, particularly droughts and floods (ADB 2001).

Droughts and floods

Although detailed historical records on the frequency and severity of droughts and floods do not exist, some severe droughts and their effects were recorded in court chronicles (Stuart-Fox 1998). Recent records clearly indicate the high level of both incidence and significance of floods and droughts. In the 37-year period from 1966 to 2002, for every year, at least part of the country was affected by either drought or flood, or a combination of both (Table 3). The potential impact on rice production was dramatically demonstrated shortly after the LPRP came to power in 1975. As previously noted, in 1977, severe drought conditions throughout the country reduced the national rice harvest by 40% relative to that of 1976 (which was already a year of deficit), with some southern provinces experiencing a decline of up to 95% (Evans 1988). It was estimated that more than 350,000 t of rice aid were required to prevent famine conditions in 1977. In 1978, a disaster of the reverse order—serious flooding— occurred. In some areas of central and southern Laos, crop losses on the order of 90% were reported. At the time, it was estimated that half the population was potentially affected by famine conditions. In both years, without reserve stocks of rice, the government depended on rice donations from the international community to avert potentially serious catastrophes. It was partly in response to the impact of the 1977 and 1978 disasters that the socialist government initiated the agricultural cooperatives movement in an effort to improve rice production and achieve a higher level of rice self-sufficiency. In 1988 and 1989, severe droughts cut annual yield by about one-third, again forcing the government to rely on food aid for its domestic requirements. In 1988 and 1989, approximately 140,000 t of rice were donated or sold to Laos (Hopkins 1995).

Table 3. Occurrence of damage to rice crops by floods and droughts, 1966-2002.

Year	Type of damage	Region affected
1966	Severe flood	Central
1967	Drought	Central, southern
1968	Flood	Central
1969	Flood	Central
1970	Flood	Central
1971	Severe flood	Central
1972	Flood and drought	Central
1973	Flood	Central
1974	Flood	Southern
1975	Drought	All regions
1976	Flash flood	Central
1977	Severe drought	All regions
1978	Severe flood	Central, southern
1979	Drought and flood	Northern (drought), southern (flood)
1980	Flood	Central
1981	Flood	Central
1982	Drought	All regions
1983	Drought	All regions
1984	Flood	Central, southern
1985	Flash flood	Northern
1986	Flood and drought	Central, southern
1987	Drought	Central, northern
1988	Drought	Southern
1989	Drought	Southern
1990	Flood	Central
1991	Flood and drought	Central
1992	Flood and drought	Central (flood and drought), northern (drought), southern (flood)
1993	Flood and drought	Central, southern
1994	Flood and drought	Central (flood and drought), southern (drought)
1995	Flood	Central, southern
1996	Flash flood, drought	Central
1997	Flood	Central, southern
1998	Drought	All regions
1999	Flood	Central, southern
2000	Flood	Central, southern
2001	Flood	Central, southern
2002	Flood	Central, southern

Source: Unpublished reports of Department of Meteorology, Ministry of Agriculture and Forestry.

More recently, in 8 of the 12 years from 1991 to 2002, significant areas of lowland rice in the Mekong River Valley were destroyed by floods (Table 4). In 1991, more than 21% (about 70,000 ha) of the rice area was destroyed; in 1995, almost 30% of the planted area in the central agricultural region was destroyed; whereas, in 1996, 17.5% and 18.7% of the rice area in the central and southern agricultural regions, respectively, were destroyed. As periods of submersion associated with the flooding of the Mekong River can often extend beyond 2 weeks, total crop loss usually results in areas affected by flooding. Some areas particularly prone to flooding have

Table 4. Wet-season lowland crop losses (ha destroyed) due to flood damage, 1991-2002.

Region	Year							
	1991a	1994	1995	1996	1997	2000	2001	2002
Central								
(ha)		28,783	55,061	41,863	26,300	28,350	30,193	24,151
(%)		(13.7)	(29.0)	(17.5)	(10.2)	(10.6)	(11.4)	(8.5)
Southern								
(ha		3,135	5,759	23,720	6,750	14,530	11,790	8,103
(%)		(2.6)	(4.9)	(18.7)	(5.2)	(11.0)	(8.2)	(5.3)
Northern								
(ha)		4,464	1,500	354	225	20	240	1,810
(%)		(8.3)	(2.5)	(0.5)	(0.3)	(<0.1)	(0.3)	(2.2)
Total								
(ha)	70,000	36,382	62,820	65,937	33,275	42,900	42,223	34,064
(%)	(21.3)	(9.5)	(16.9)	(15.3)	(7.9)	(9.0)	(8.7)	(6.6)

[a]Regional flood damage data are unavailable. Sources: Ministry of Agriculture and Forestry and the Ministry of Labor and Social Welfare.

recently been withdrawn from wet-season cropping activities following the development and expansion of the potential for dry-season irrigated cropping. Flooding in the northern mountainous agricultural region is usually of short duration and crops can sometimes recover from the impact of such floods; however, the nature of floods is such that they are potentially capable of causing significant levels of soil erosion, particularly in areas with a history of intensive slash-and-burn agriculture.

Drought, although less spectacular than devastating floods, is a regular occurrence throughout the rice-growing areas of Laos (Table 3). Farmers in the rainfed lowland environment of the Mekong River Valley consider drought as their most consistent production constraint (Khotsimuang et al 1995). The soils in this region are predominantly loams, sandy loams, and sands, and are particularly drought-prone (Lathvilayvong et al 1996). Although the effects of drought can often be less severe than those of floods, drought usually affects a much larger area than floods. Both early and late wet-season droughts occur and affect rice production (Fukai et al 1998). Early-season drought usually occurs from mid-June to mid-July as the monsoons change from southeast to southwest. The effects of this type of drought can be reduced by appropriate crop management practices, particularly by matching crop phenology with water availability (Fukai et al 1998). Late-season drought occurs if the regular monsoon rains end early. Fukai et al (1995) have demonstrated that late-season drought alone can reduce grain yields by an average of 30%. The use of earlier maturing improved varieties to replace later maturing, and often lower yielding, traditional varieties can significantly reduce the potential impact of late-season drought. Fukai et al (1998) also demonstrated that the effect of drought on grain yield also depends on soil fertility, and that improved soil fertility increases grain yield, even in drought-affected seasons.

The occurrence of drought in uplands is equally as frequent and can be equally as severe as in lowlands. Lebar and Suddard (1960) reported on the occurrence of a serious drought throughout much of northern Laos in 1955, the severity of which was so great that rice was flown in on U.S. planes and dropped by parachute to villagers in order to avert potential starvation. Although ranked third among production constraints by upland farmers (Roder et al 1997), the impact of drought in the upland environment is of increasing significance and concern. Dry conditions in this environment have the greatest impact when occurring at or about the time of dry-seeding, affecting both germination and establishment. Late-season drought (i.e., when the wet-season rains end early) is not normally a concern, as most upland crops are harvested 30 to 50 days earlier than lowland crops in the same region.

Even with the recent increase in the area of cultivation under irrigated conditions (Table 2), the majority of both the planted area and production in Laos will remain at the mercy of the vagaries of the weather for the foreseeable future. However, it is possible to achieve greater yield stability under such conditions through varietal improvement.

Biotic disasters

Pests and diseases are also chronic production constraints for both upland and lowland environments (Schiller et al 2001). Normally, their impact is relatively localized and often the implementation of appropriate management practices can minimize their potential damage to rice crops. However, one category of pest in upland environments that has traditionally had an impact on production often of the same magnitude as natural disasters is rodents (Roder et al 1997, Singleton et al 1999). Although actual grain losses due to rodents have yet to be quantified, it is estimated that they probably account for at least 15% of the annual rice harvest (Singleton and Petch 1994). At irregular intervals, conditions favor massive rodent population explosions, resulting in local losses of more than 50% of the rice crop. Occasionally, entire rice crops are lost, as happened in parts of Luang Prabang Province in 1991.

National rice sufficiency

Rice production in Laos has generally been on the basis of meeting immediate household needs. In the absence of an established market for rice, until recently, there has been little incentive to produce a rice surplus, particularly under upland conditions. As a result, small fluctuations in yield caused by climate, pest problems, or labor shortages have usually been immediately reflected in rice shortages (Roder et al 1996). These authors also report that occasional shortages of rice are not a recent phenomenon. Observations in the uplands as long ago as the early 1940s report rice stores often being empty in July, forcing farming families to rely on hunting and gathering for provisions for periods of 3–4 months before the harvest of the next rice crop.

Independent of the impact of the vagaries of the weather and pest problems, changes in the level of rice self-sufficiency have, until relatively recently, often reflected the level of political stability throughout the country. During the period of French administration from 1893 to 1945, there was considerable resistance of many ethnic groups to a number of government policies. In particular, resistance was strong to some of the taxation measures, as well as the system of annual unpaid labor that was imposed (Batson 1991, Simms and Simms 1999). The often physical resistance of some ethnic groups to the implementation of these laws and measures was associated with a lack of stability in many upland areas, which interrupted normal upland rice-cropping cycles. As a result, during the period of French administration, significant areas of Laos often had periodic and chronic rice shortages because of factors other than the impact of natural disasters and pest damage. Total annual rice production during this period fluctuated from a maximum of just over 500,000 t in 1923 to an average of less than 300,000 t during the 1930s. In upland areas, shortages were made up by maize (from upland swiddens) and various tuber crops. However, in lowland areas, the deficits were not so readily replaced by alternative foods. A 20% decline in the national rice harvest in 1936 was associated with subsequent near-starvation conditions in parts of Khammouane Province. After Lao independence in 1953, under the Royal Lao government there was a 20-year period during which the disruptive effects of the ongoing civil conflict in much of the country also disrupted the normal rice-cropping cycles, in both upland and lowland environments. For much of this time, there was a chronic national rice deficit, with shortages at both regional and local levels often being critical. In the upland environment, the frequent displacement of villages in some areas generally meant that the rice shortages were more acute than in lowland areas. At the height of the conflict in the 1960s and early 1970s, tens of thousands of members of mainly upland ethnic groups fled their villages to avoid the fighting in the north of the country, while the Plain of Jars in the northeastern region was almost depopulated (Stuart-Fox 1997). Stuart-Fox (1997) reports that during this time "as many as three-quarters of a million people, a quarter of the entire population, had been driven from their homes to become refugees in their own country." In some remote areas, displaced villages became totally dependent on food supplies dropped by American planes. At the peak of the shortages in the early 1970s, more than 170,000 refugees were understood to be dependent on receiving rice in this way in the north of the country alone. The rice used for these "sky drops" was all imported. It was even reported that some young children of this era came to believe that "rice came from the sky." Appa Rao et al report that some of this "rice from the sky" was used as seed for planting, and was still being planted at the time varieties were collected for conservation and preservation in the latter part of the 1990s, having been given the varietal name "American rice." Batson (1991) reports that it was not until 1984 that some degree of national rice self-sufficiency was first achieved. However, even for that year, the same author noted that "a combination of uneven production, poor land, poor transportation, and climatic vagaries left people in the rugged, highland areas without enough rice or with very marginal surpluses."

In the main areas of lowland rice cultivation, rice self-sufficiency from year to year has primarily reflected the occurrence of natural disasters—droughts and floods, and occasionally pest and disease problems. At a national level, the decision in the early 1990s to expand the area of irrigated rice production has, in association with the adoption of improved production practices in lowland environments, brought about a rapid change in the reported level of national rice self-sufficiency. Production from the 2001 dry-season irrigated environment accounted for about 19% of total production for that year, compared with less than 3% coming from the irrigated environment in 1990.

Although the official statistics of the Ministry of Agriculture and Forestry indicated that national rice self-sufficiency was achieved in 1999 with the production of 2.1 million tons of paddy rice (Table 2), with further increases in subsequent years to in excess of 2.4 million tons in 2002, unofficially it is acknowledged that these figures are overestimates. It has also been long acknowledged that national rice self-sufficiency does not necessarily translate into regional, provincial, or household self-sufficiency. Rice surpluses of recent years in areas with double-cropping potential as a result of the expansion of irrigated rice cultivation have not necessarily alleviated the increasing chronic rice shortages of many upland areas. Recent studies on poverty and human development in Laos (ADB 2001, UNDP 2000) reveal that 90% of villages classified as poor throughout the country depend on swidden agriculture as their primary means of livelihood. Levels of poverty are closely linked to levels of food (primarily rice) sufficiency. Generally speaking, the level of rice deficiency is currently greatest within Mon-Khmer groups in upland areas and least in the Tai-Lao, who predominately inhabit the lowlands (Table 5). Rice shortages in the uplands generally average 3–4 months but can be as much as 8 months and are chronic; in the lowlands, they average 1–3 months and vary from year to year, depending on natural disasters, particularly drought and floods, and place to place, reflecting irrigation potential and the availability of land.

Table 5. Levels of rice sufficiency (months per year) according to region and ethnicity.

Region	Ethnicity			
	Mon-Khmer	Tibeto-Burman	Hmong-Mien	Lao-Tai
North	6.2	7.0	8.2	11.5
East	6.3	–	7.8	6.5
Central	7.9	–	8.0	10.8
South	5.5	–	–	9.3
Average	5.9	7.0	8.1	9.0

Source: UNDP (2002).

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Swetha–a new, medium-duration variety with multiple tolerance released in Kerala, India

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In Kerala, biotic stresses such as blast, sheath blight, bacterial blight, sheath rot, gall midge biotype 5, and stem borers are the major factors that limit the yield of rice varieties developed for the rabi (wet) season. Besides these, abiotic stresses such as iron toxicity and phosphorus deficiency prevail in some parts of the state. One breeding objective therefore was to develop a medium-duration variety with multiple tolerance to suit rabi-season cultivation. High-yielding variety IR50 was crossed with C14-8, a late-duration (170–175 d), photoperiod-sensitive traditional cultivar from Andaman Islands, India. It has resistance to/tolerance for biotic and abiotic stresses such as blast, bacterial blight, sheath blight, rice tungro disease, iron toxicity, phosphorus deficiency, and salinity (Majumder et al 1995).

The culture RPP7-23-1-2-3, derived from the cross IR50/C14-8, with 106–110-cm plant height and 135–140-d duration, showed high yield potential and multiple resistance/tolerance for disease and insect pests. It was evaluated as IET14735 in the All India Coordinated Rice Improvement Program from 1995 to 1998 in southern states of the country, along with national checks Jaya and Suraksha, local checks, and other entries developed elsewhere. In Kerala, it was evaluated in seven trials at three locations. The yield of IET14735 ranged from 4.2 to 7.4 t ha^{-1} (mean, 5 t ha^{-1}). Over years and locations, IET14735 showed 24.7%, 16.7%, and 15.4% higher yield than did Jaya, Suraksha, and local variety Neeraja, respectively (Table 1). In Maharashtra, IET14735 was evaluated in nine trials with the same set of materials, except for the local check varieties. It yielded 3.85 t ha^{-1} over years and locations, with a yield advantage of 51.6%, 19.9%, and 18.8% over Jaya, Suraksha, and Mandya Vijaya, respectively. Considering its yield superiority and multiple tolerance for diseases and insect pests, IET14735 was recommended for on-farm trials in Kerala in 2000.

In on-farm trials conducted at Palakad District (normal soil condition), IET14735 gave the highest yields in both rabi seasons of 2000-01 (6.6 t ha^{-1}) and 2001-02 (4.8 t ha^{-1}). At Thrissur,

Table 1. Yield performance of variety Swetha in the All India Coordinated Trials.

State	Year of testing	Locations (no.)	Yield (t ha^{-1}) Swetha (IET14735)	National checks Jaya	National checks Suraksha	Local check	Percent increase over Jaya	Suraksha	Local check	Local check variety
Kerala	1995	1	5.0	2.7	4.1	4.6	85.4	21.3	7.1	Neeraja
	1996	1	4.2	4.1	4.1	3.7	3.9	3.9	9.0	Neeraja
	1997	3	6.0	4.2	4.5	4.0	42.8	32.4	49.9	Adhira
	1998	2	4.6	4.9	4.3	4.7	-6.1	7.7	–	Neeraja
Mean			5.0	4.0	4.2	4.3	24.7	16.7	15.4	
Maharashtra	1995	2	3.5	2.3	2.9	2.4	51.3	21.3	49.4	SKL-7
	1996	1	4.9	1.1	3.2	4.7	347.7	53.9	3.6	Mandya Vijaya
	1997	3	3.8	3.6	3.6	3.4	4.9	5.9	11.8	Mandya Vijaya
	1998	3	3.2	3.1	3.3	2.5	2.9	–	28.7	Mandya Vijaya

where farmers' iron-toxic fields were used in the adaptive trials, it yielded 3.3 t ha^{-1} and was among the top three yielders. It also obtained the highest yield among six varieties at each of the following fertilizer levels—120-60-60 kg NPK ha^{-1}, 60-30-30 kg NPK ha^{-1}, and no fertilizer.

Considering its yield superiority over check varieties in national coordinated trials and adaptive trials in farmers' fields, its high nutrient-use efficiency, and its multiple tolerance for diseases and insect pests, IET14735 (RPP7-23-1-2-3) was released as variety Swetha for cultivation in the rabi season in the state of Kerala in 2002. A summary of the important characteristics of Swetha is given in Table 2.

Reference

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Table 2. Morphological characteristics of variety Swetha.

Characteristic	Item
Plant height	106–110 cm
Flag leaf	Erect
Leaf sheath color	Green
Ligule	Pale green
Collar	White
Leaf at maturity	Green, late senescence
Stigma color	Cream
Outer glume color	Straw with brown tinge
Lemma & palea	Straw with brown tinge
Awn	Absent
Panicle	Well exserted
Panicle length	28.5 cm
Seed coat color	Straw with brown tinge
Photoperiod reaction	Photoperiod insensitive
Dormancy	Moderately dormant
Maturity range	
Kharif	140–145 d
Rabi	135–140 d
Grain characteristics	
Length	5.98 mm
Width	2.64 mm
Length/breadth	2.27
Shape	Slender bold
Hulling (%)	76.5
Milling (%)	71.5
Head rice recovery (%)	67.6
Abdominal white	Occasional
Kernel appearance	White
Test weight (1,000 grains)	22.37 g
Alkali value	5.0
Reaction to major diseases	Resistant to blast; moderately resistant to bacterial blight, rice tungro disease, brown spot, sheath blight, sheath rot
Reaction to major pests	Moderately resistant to gall midge, whitebacked planthopper, and stem borer

Hybrid rice varieties released in Maharashtra, India

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Rice is the major cereal food grain in the Konkan region, in Maharashtra State, and in India. Maharashtra contributes 3.7% in terms of area and 2.8% in terms of rice produced at the national level. The total area under rice in this state is about 1.5 million ha. Annual rice production is about 2.5 million t and average productivity is 1.7 t ha^{-1}. Area, production, and productivity have been nearly stable in the last two decades. Rice is mainly a rainfed crop of small and marginal farmers (90%) in the state and there has been no substitute crop to sustain their livelihood since 1970. Four agricultural universities in Maharashtra have developed and released a total of 54 high-yielding varieties (HYVs) through conventional breeding programs. The yield of HYVs remained stable at 4–4.5 t ha^{-1}. The RARS in Karjat is the main research and coordinating center for the rice crop improvement program in Maharashtra.

Hybrid rice has long been recognized to have potential to enhance productivity. The Indian Council of Agricultural Research (ICAR) initiated a project on hybrid rice in December 1989. Implemented through a national research network involving 12 centers, including the Karjat center in Maharashtra, this program was coordinated by the Directorate of Rice Research in Hyderabad. Additional technical and financial support from the International Rice Research Institute, the United Nations Development Programme, MRF, and the Asian Development Bank further strengthened the hybrid rice program. Work on hybrid rice began in 1992 at RARS Karjat. Research on heterosis breeding was intensified at this center with the inception of the NATP-Hybrid Rice Project in 1999. The continuous breeding efforts yielded various hybrid combinations, developed through a three-line breeding method using cytoplasmic male sterile lines. Some of the promising hybrids were released for commercial cultivation in the state.

The salient features of rice hybrids developed and released by RARS are given in the table. Sahyadri was the first rice hybrid released from RARS in 1998 and was distributed for commercial cultivation in 2000. It is medium duration (125–130 d) and has average yield potential (6.0–6.5 t ha^{-1}) and mid-tall stature (115–120-cm height). It has long slender grain, with 1,000-grain weight of 26.0 g. The milling percentage of Sahyadri is 67.3; head rice recovery is 51.5%.

Sahyadri-2, on the other hand, is an early duration (115–120 d) rice hybrid. It has better grain

Table 1. Distinguishing features among the three hybrids developed by RARS, Karjat center.

Feature	Sahyadri	Sahyadri-2	Sahyadri-3
Designation	KJRTH-1	KJRTH-3	KJRTH-12
Days to 50% flowering	95–100	85–90	95–100
Days to maturity	125–130	115–120	120–125
Tillering habit	Profuse 12–15/hill	Profuse 20-25/hill	Profuse 15–17/hill
Height (cm)	115–120	105–110	115–120
Plant type	Compact	Compact	Compact
Panicle exsertion	Well exserted	Moderately well exserted	Well exserted
Panicle length (cm)	22	25.5	28.0
Awns	Absent	Absent	Absent
Aroma	Mild	Mild	Optimum
Grain type	Long slender	Long slender	Long slender
No. of spikelets/panicle	180–200	178–225	195–220
Kernel length (mm)	7.18	6.63	7.51
Kernel breadth (mm)	2.39	2.18	2.22
LB ratio	3.004	3.04	3.38
Grain chalkiness	Occasionally chalky	VOC	Absent
Amylose (%)	21.9	22.77	24.8
Test weight of 1,000 grains	26.0	23.5	28.1
Milling percentage	67.3	70.2	74.5
Head rice recovery (%)	51.5	56.0	60.2
Grain yield (t ha^{-1})	6.0–6.5	6.0–6.5	6.5–7.0
Test quality after cooking	Desirable	Good (5.3)	Good (6.0)
Swelling after cooking	Breadth-wise swelling	Breadth-wise swelling	Breadth-wise swelling
Overall acceptability	Acceptable	Good	Good
Major disease resistance	Moderately tolerant resistant to leaf blight	Resistant to neck blast, highly resistant to false smut, moderately resistant to, bacterial leaf blight to resistant to sheath rot moderately resistant to, stemborer resistant to, brown planthopper	Resistant to neck blast and moderately leaf blast to bacterial leaf blight resistant to leaf folder, moderately resistant to whitebacked planthopper
Major insect and pest resistance	–		
Straw yield (t ha^{-1})	7.5–8.0	7.0–7.5	7.5–8.0
Harvest index (%)	44.84	46.42	46.66
Seed production characteristics			
Days to 50% flowering for female line	Kharif—87–90	Kharif—87–90	Kharif—87–90
	Rabi—105–108	Rabi-105–108	Rabi—105–108
Days to 50% flowering for male line	Kharif—97–100 Rabi—128–130	Kharif—83–86 d Rabi—100-103	Kharif—100–105 Rabi—123–125
Sowing pattern for proper synchronization between male and female	R_1–1st day	A line–1st day	R_1–1st day sowing
	R_2 – 6th day after 1st sowing	R_1 – 5 days after sowing of A line	R_2 – 6th day of 1st sowing
	R_3 –11th day after 1st sowing	R_2 – 5 days after R_1 line sowing	R_3 – 11th day of 1st sowing
	Female line–23rd day of R_1 sowing	R_3 – 5 days after R_2 line sowing	Female line–24 days after 1st date of R line sowing
Height of female line (cm)	80–85	80–85	80–85
Height of male line (cm)	105–110	98–105	115–120
GA_3 spraying	On female line only	On male & female lines	On female line only
GA_3 recommended dose	60 g ha^{-1}	60 g ha^{-1}	60 g ha^{-1}

quality (long and slender), 1,000-grain weight of 23.5 g, good milling percentage (70.2%), and good head rice recovery (56%). Intermediate amylose content is 22.8%. It has an average yield potential of 6–6.5 t ha^{-1} with multiple disease and insect pest resistance (highly resistant to false smut; resistant to neck blast; moderately resistant to sheath rot, bacterial leaf blight, rice tungro virus, and stem borer). Sahyadri-2 is suitable for upland and double-cropped areas in the state and was recommended for commercial cultivation in Maharashtra in 2004.

Sahyadri-3 is a medium-duration (125–130 d), mid-tall (115–120 cm), long slender grain type, with an average grain yield potential of 6.5–7.0 t ha^{-1}. It has given a 5–10% yield increase over Sahyadri in farm trials, state and national coordinated trials, and in farmers' fields. Sahyadri-3 has greater milling percentage (74.5%) and head rice recovery (60.2%) than Sahyadri.

Genetic contribution of ancestors to Nepalese rice cultivars

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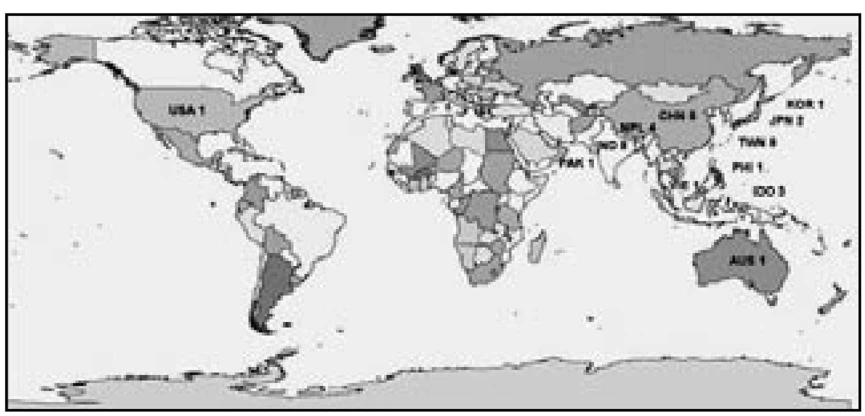
Nepal is divided into three agroecological zones—tarai, mid-hill, and high hill. Research on rice, Nepal's most important crop, is conducted on the basis of what these zones require and recommendations are made accordingly. The mid- and high hills have more diverse climatic conditions than the tarai. Diverse landraces are being cultivated and maintained in these areas to meet various needs of farmers. However, genetic uniformity has been observed after the release of some cultivars. This became a major concern to plant breeders after the 1970 corn leaf blight incidence. The objective of this study was to determine the relative genetic contribution of ancestral lines of Nepalese rice cultivars recommended for the mid- and high hills of Nepal. Knowing the genetic background of these cultivars would be useful in breeding programs to widen the genetic base and increase yield.

The genetic base of 20 rice cultivars, which were recommended for the mid- and high hills, was studied. The parental contribution of an ancestral genotype to a modern cultivar was determined following the procedure of Delannax et al (1983). Ancestors were defined as founding stocks with no known pedigree. The contribution of an ancestor was defined as the fraction of the genes in modern cultivars that could be traced from the progeny of that ancestor through pedigree analysis. The genetic contribution corresponds to the theoretical proportion of genes coming from an ancestor, assuming that every time a cross is made, 50% of the genes come from each parent.

A total of 47 ancestors originating in 12 countries were used to develop 20 Nepalese rice cultivars that were recommended for the mid- and high hills (figure). The analysis revealed that the genetic base of these recommended



Countries where ancestors of Nepalese improved rice cultivars recommended for the mid- and high hills originated. (Origins of nine ancestors are not known.)

cultivars was fully defined by 47 ancestors. These ancestors' contribution to the genetic base varied from 0.04% to 11.2% (Table 1). A restricted number of ancestral genotypes accounted for a large proportion of the variation in the released cultivars. The highest contribution was from Dee-geo-woo-gen, which was used in 12 cultivars. Eight ancestors contributed 50%. Most of the cultivars were developed using fewer than four ancestors, indicating a narrow genetic base. With a greater number of parents, fewer alleles are fixed and more genetic variation is retained (St. Martin 1982). This shows that rice breeders have made progress at the expense of losing substantial portions of genetic variation originally available.

Table 1. Ancestors' contribution to the genetic base of Nepalese rice cultivars.

Ancestor	Origin	Contribution (%)	Cumulative contribution (%)	Varieties contributed (no.)	Variety	Ancestors used to develop variety (no.)
Dee-geo-woo-gen	Taiwan	11.2	11.2	12	Chianan 2	3
Ghandruk Local	Nepal	7.5	18.7	2	Chianung 242	4
Pokhreli Masino	Nepal	7.5	26.2	3	Chandhanath 1	1
Fuji-102	Japan	5.0	31.2	2	Chandhanath 3	1
Jinling-78-102	China	5.0	36.2	1	Chhommrong	1
Tsai Yuan Chung	Taiwan	5.0	41.2	2	Himali	5
Yunlen-1	China	5.0	46.2	1	Kancahn	13
Jerak	?	4.4	50.5	4	Khumal 4	13
Cina	China	3.8	54.3	10	Khumal 5	5
Latisail	Pakistan	3.8	58.2	10	Khumal 7	5
Kn-1b-214-1-4-3	Indonesia	3.8	61.9	1	Khumal 11	3
Akiyudaka	Korea	2.5	64.4	1	Khumal 2	5
China 1039	India	2.5	66.9	1	Khumal 3	6
China-1039-DWF-MUT	China	2.5	69.4	1	Khumal 6	17
Jarneli	Nepal	2.5	71.9	1	Khumal 9	2
Kulu	Australia	2.5	74.4	1	Machhapuchhre 3	2
Taichung-65	Taiwan	2.5	76.9	1	Manjushri 2	19
Gp-15	?	1.7	78.6	4	Palung 2	6
China 971	China	1.3	79.9	1	Taichung 176	2
Dunghan Shalil	?	1.3	81.1	1	Tainan 1	2

Table 2. Origin of ancestors and their contribution to Nepalese rice cultivars.

Country	Cumulative contribution (%)	Number contributed		Group/	Cumulative	Number contributed	
		Cultivars	Ancestors	species	contribution (%)	Cultivars	Ancestors
Taiwan	24.8	14	9	Indica	48.2	13	23
Nepal	18.1	7	4	Japonica	33.1	9	11
China	17.6	14	5	Unknown	18.7	13	13
India	6.4	6	9				
Japan	6.3	3	2				
Indonesia	5.3	5	3	*sativa*	99.8	16	46
Pakistan	3.8	10	1	*nivara*	0.2	4	1
Australia	2.5	1	1				
Korea	2.5	1	1				
USA	0.4	4	1				
Vietnam	0.2	2	1				
Philippines	0.0	1	1				
Unknown	12.2	10	9				

Many researchers have reported similar results. Dilday (1990) found a narrow genetic base for the southern rice belt; he traced back to 22 ancestors 140 lines from the U.S. rice breeding programs. Ten introductions contributed collectively to >80% of the northern gene pool of soybean (Delannax et al 1983). In barley, five ancestors contributed more than 50% of the genetic makeup of released cultivars (Martin et al 1991).

The origin of most of the ancestors of these Nepalese cultivars was Taiwan (19.1%), India (19.1%), China (10.6%), Nepal (8.5%), Indonesia (6.4%), and Japan (4.3%). On the basis of contribution, ancestors from Taiwan (24.8%), Nepal (18.1%), China (17.6%), India (6.4%), Japan (6.3%), and Indonesia (5.3%) constituted 78.4% of the total contribution (Table 2). Most of the predominant introductions came from the same geographical areas. Ancestors from China and Taiwan each contributed to 14 cultivars, followed by those of Pakistani origin. About 50% of the ancestors were of the indica type, which contributed 48.2%. Only two species, *sativa* and *nivara*, were used. The mid- and high hills are relatively cool regions where japonica-type landraces are being cultivated. However, the contribution of indica-type ancestors was high in these released cultivars. The diversity present at the species and varietal levels should be considered in planning breeding programs to control genetic erosion and vulnerability, which is a great possibility because of the observed genetic uniformity. Reshuffling the genetic constituents is also necessary to increase yield potential.

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IRH1—the first aromatic hybrid rice in Iran

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Increasing rice production in Iran, a country with limited land and water resources, is a challenging task, especially with consumer demand largely favoring varieties with superior grain quality. In 2000, Iran imported 1.2 million t of rice. But, in recent years, with increased adoption of improved varieties and with favorable climatic conditions, importation has been reduced to 0.98 million t (FAO 2006). However, with recent fluctuations in the availability of surplus rice from rice-exporting countries and the increasing rice demand in Asia alone, Iran has to initiate a well-drawn plan to attain self-sufficiency and sustain its rice production in the long term. Among the available approaches, the most viable is to pursue hybrid rice technology for Iran, on the basis of success achieved in India, Vietnam, and the Philippines. Hybrid rice technology could easily deliver hybrids with medium quality in the short term, with a 1.5–2.0 t ha^{-1} advantage over improved check varieties (such as Khazar), while superior quality with high yield can be combined in the hybrids, provided a systematic approach is followed.

A comparative yield trial in 2002 involving four promising hybrids and their parents and inbred check variety Khazar revealed exceptional performance of the hybrid combination IR58025A/IR42686R. This hybrid gave the highest standard heterosis (57.9%), heterobeltiosis (53.3%), and commercial heterosis (45.2%) over improved check variety Khazar (Table 1). Furthermore, the number of days to 50% flowering of the parents differed by only 3, with the R line flowering earlier and having a relatively better quality than Khazar (data not shown).

A pooled analysis of variance for the adaptive yield trial conducted over two different sites for 2003-04 showed significant yield differences among genotypes and in site-by-genotype-by-year interaction. IR58025A/IR42686R gave an average yield of 9.2 t ha^{-1} with a yield advantage of 28% over Khazar (Table 1). It was named IRH1.

On-farm trials conducted in 2005 at four locations gave an impressive yield of 12 t ha^{-1}, which was 85% higher than Khazar's 6.5 t ha^{-1} (Table 2). The hybrids

Table 1. Yields (kg ha^{-1}) of IRH1 (IR58025A /IR42686R) and check varieties in advanced yield and adaptive trials and associated heterosis (%) based on means across sites.[a]

Genotype	Rasht*	Chaparsar*	Mean*	Standard heterosis	Hetero-beltiosis	Commercial heterosis
Advanced yield trial, 2002						
IR58025A /IR42686R	8,964 A	9,425 A	9,195 A	57.9	53.3	45.2
IR42686R	5,480 J	5,822 I	5,651 J	–	–	–
IR58025B	5,872 H	6,125 G	5,998 G	–	–	–
Khazar (inbred check)	6,445 F	6,220 F	6,332 F	–	–	–
Adaptive research trial, 2003-04						
IR58025A /IR42686R	8,964	9,425	9,195	–	–	28.0
IR42686R	5,651	5,425	5,568	–	–	–
Khazar (inbred check)	6,942	7,422	7,182	–	–	–

[a]In the advanced yield trial, means followed by different letters in a column are significantly different from each other using DMRT.

responded better to agronomic management than did inbreds because of the former's heterozygosity. Early sowing by 20 d in Anzali contributed to higher yields than those obtained in Rasht. The performance of IRH1 at Anzali in the last two consecutive years earned for it the top prize in crop yield competition conducted by the Ministry of Jihad-e-Agriculture, Iran. This also indirectly led to increased seed demand from the provincial agricultural organizations of Guilan and Mazandaran—60 t each for the 2007 cropping season. However, only 40 t of IRH1 seed was to be produced in the 2006 cropping season to cover 2,000 ha.

Production of IRH1 seed is currently being done on 40 ha with the involvement of the public sector and trained private entrepreneurs. Current seed production yields varied between 1.0 and 1.6 t ha^{-1}. In time, yield may reach 2.5 t ha^{-1} in areas where favorable conditions prevail such as in Dasht-e-Naz, near Sari, Mazandaran Province.

The agronomic and quality characteristics of IRH1 in comparison with those of its parents and improved inbred check variety Khazar are given in Table 3. IRH1 has a semidwarf (118 cm) stature, with 19 productive tillers and 196 grains panicle^{-1}. It matures together with Khazar in 130 d. Its head rice recovery (62%) makes it quite attractive to millers and its quality is comparable with that of popular inbred variety Khazar. It has aroma, intermediate amylose (22.1%), and better gel consistency (GC) (54 mm) and gelatinization temperature (GT) (score of 5.6) than Khazar, which has no aroma, higher amylose (25.7%), and lower GC (44 mm) and GT (score of 5). It has good cooking quality, resistance to blast, and moderate tolerance for stem borers.

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Table 2. Yields (t ha^{-1}) of IRH1, Khazar (improved inbred check), and Hashemi (premium-quality check) in on-farm trials conducted at four locations in 2005.

Entry	Pirbazar	Masal	Anzali	Rasht	Mean
IRH1	12.5	12	14.5	8.9	12
Khazar	6.5	6.7	7.2	5.7	6.5
Hashemi	4.5	4.5	4.7	4.4	4.5

Table 3. Agronomic and grain quality characteristics[a] of IRH1 in comparison with those of its parent and improved check variety Khazar.

Characteristic	IRH1	IR58025[b]	IR42686R	Khazar
Agronomic traits				
Plant height (cm)	118	106	113	126
Productive tillers plant^{-1} (no.)	19	12	22.2	12
Maturity (d after sowing)	130	140	135	130
Grains panicle^{-1} (no.)	196	97	140	135
Grain quality traits				
Total milled rice recovery (%)	70.9	69.4	72	68.5
Milled head rice recovery (%)	61.9	60.7	62.3	60.3
Broken rice (%)	9.0	8.7	9.7	8.2
Shape	Long slender	Long slender	Long slender	Long slender
Aroma (present/absent)	Present	Present	Partially present	Absent
Grain length (mm)	10.0	9.8	9.5	10.2
Kernel length (mm)	7.0	6.26	6.2	7.1
Kernel width (mm)	2.0	1.56	1.7	2.0
Kernel length/width	3.5	4.01	3.5	2.9
Cooked kernel length (mm)	9.76	9.56	9.16	10.62
Cooked kernel width (mm)	2.5	2.8	2.7	2.8
Cooked kernel length/width	3.9	4.3	3.5	3.8
Elongation ratio (lengthwise)	1.4	1.4	1.5	1.5
Amylose (%)	22.1	17.0	23.7	25.7
Gel consistency (gel length in mm)	54	72	44	44
Gelatinization temperature (alkali spreading value score)	5.6	7.0	5.4	5.0

[a]All traits were measured according to IRRI's (1996) *Standard evaluation system*. [b]IR58025A (female parent) was used for agronomic trait evaluation. The isogenic B line was used to assess grain quality traits.

HUBR 2-1 (Malviya Basmati Dhan 1), a new, high-yielding basmati rice variety for cultivation in eastern India

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Basmati rice, praised for its unique quality, is a connoisseur's delight and nature's gift to the Indian subcontinent. It is endowed with exquisite aroma, fine long slender grains, and unique cooking quality traits that play a major role in ensuring consumer acceptance globally. Basmati rice thus fetches a premium price in domestic and international markets. Most of the traditional basmati varieties are tall, low-yielding, and susceptible to pests and diseases. In this research, great efforts were exerted to develop a short, high-yielding basmati variety with pest and disease resistance to make basmati cultivation remunerative to farmers and to sustain basmati rice exports from India. HUBR 2-1 was developed from the three-way cross HBR 92/Pusa Basmati-1//Kasturi. Segregating generations of the cross were handled by pedigree selection from the F_2 generation onward to select true breeding lines that show good plant type and distinctive quality and yield traits. New, high-yielding basmati line HUBR 2-1 was selected by single-plant selection, a direct comparative method in field trials.

Fourteen quality traits of HUBR 2-1 were assessed using standard procedures and compared with those of popular basmati varieties (Table 1). In coordination with the Directorate of Rice Research, Hyderabad, the yield performance of this entry was tested in the Uttar Pradesh station varietal trials at different locations in four zones during the 1996-99 wet season. HUBR 2-1 consistently outyielded all other recognized basmati check varieties over all locations in all zones. Pooled analysis indicated significant differences in grain yield, with HUBR 2-1 giving 48.5%, 59.7%, 37.7%, and 71.9% yield advantage over Basmati 370, Type 3, Pusa Basmati 1, and Taroari Basmati, respectively (Table 2).

HUBR 2-1 was tested as IET16318 in the All India Coordinated Varietal Trial in the 1998 wet season in four traditional basmati- (six locations) and three nontraditional basmati- (five locations) growing states. HUBR 2-1 was the top yielder in all locations (Table 3), with the yield advantage ranging from 31.3% to 66.0% over popular basmati checks. Besides having high yields, good quality, and good cooking traits, it was also tolerant of blast, bacterial leaf blight, and stem borer. It was also tested in some farmers' fields and it is expected to cover

Table 1. Grain quality traits of HUBR 2-1 and check varieties Pusa Basmati 1 and Taroari Basmati.

Character	HUBR 2-1	Pusa Basmati 1	Taroari Basmati
Milling recovery (%)	71.3	67.5	65.0
Head rice recovery (%)	56.5	53.3	46.2
Kernel length (L) (mm)	7.45	8.20	7.90
Kernel breadth (B) (mm)	1.70	1.50	1.70
L/B	4.00	5.47	4.65
Shape	Long slender	Long slender	Long slender
Amylose content (%)	20.9	25.6	24.6
Alkali spreading value	5.5	7.0	5.0
Gel consistency (mm)	60	50	47
Volume expansion ratio	2.5	4.3	4.2
Kernel length after cooking (mm)	12.10	13.00	12.39
Elongation ratio	1.96	2.00	1.91
Water uptake (mL)	68.1	68.5	63.3
Aroma	Strong scent	Strong scent	Strong scent

Table 2. Zonal yield performance (t ha^{-1}) of HUBR 2-1 and four check varieties in state varietal trials, Uttar Pradesh, 1996-99 wet seasons.

Genotype	Eastern zone		Western zone		Central zone		Tarai		Overall mean	% increase over check
	Mean	% gain	Mean	% gain	Mean	% gain	Mean	% gain		
HUBR 2-1	3.23	–	4.31	–	3.76	–	3.14	–	3.61	–
Basmati 370	2.46	31.3	2.73	57.9	2.78	35.3	1.76	78.4	2.43	48.6
Basmati Type 3	2.38	35.7	2.64	85.0	2.68	40.3	1.36	130.9	2.26	59.8
Pusa Basmati 1	2.42	33.5	3.09	39.5	2.08	80.8	2.90	8.3	2.62	37.8
Taroari Basmati	2.02	59.0	2.09	106.2	2.19	71.7	–	–	2.10	71.9

Table 3. Yield performance (t ha^{-1}) of HUBR 2-1 in comparison with two checks in the All India Coordinated Varietal Trial traditional and nontraditional basmati states, 1998 wet season.

Genotype	Traditional basmati states (six locations)					Nontraditional basmati states (five locations)				Overall mean	% increase over check
	Delhi	Haryana	Rajasthan	Jammu Kashmir	Mean	Tamil Nadu	Karnataka	Uttar Pradesh	Mean		
HUBR 2-1	4.17	3.68	3.58	4.67	4.03	3.45	4.26	3.68	3.78	3.90	–
Pusa Basmati 1	3.15	2.80	3.38	2.70	3.01	1.96	3.80	3.03	2.93	2.97	31.3
Taroari Basmati	1.68	1.43	2.96	2.48	2.14	1.74	3.04	2.80	2.57	2.35	66.0

vast areas under cultivation in Uttar Pradesh, western Bihar, and parts of Madhya Pradesh. HUBR 2-1 was named Malviya Basmati Dhan 1 and was approved for general cultivation in Uttar Pradesh by the State Variety Release Committee in 2004. It was also recommended for cultivation in the irrigated areas of western Bihar.

HUBR 2-1 is semidwarf, with stiff stems, has fairly strong tillering ability (350–400 effective tillers m^{-2}) and is tolerant of blast, bacterial leaf blight, and stem borer. Its grain is long, slender, and aromatic, with 20–21% amylose. The yield of HUBR 2-1 is about 4–5 t ha^{-1}. It is expected that it will boost eastern India's export and domestic rice markets.

CN1231-11-7 (IET17792), an alternative to Sabita for the rainfed lowland ecosystem in eastern India

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Sabita is a variety that predominates in India's rainfed lowland ecosystem. In medium deepwater fields (41 to 75-cm water depth), this variety has been extensively grown by farmers in West Bengal, Assam, and Orissa. Sabita has been used as a national check in advanced variety trials–semideepwater (AVT SDW), initial variety trials–semideepwater (IVT SDW), and the National Semideepwater Screening Nursery (NSDWSN) since 1988. It has been an international check since 1992 for the Eastern India Rainfed Lowland Shuttle Breeding (IRRI-ICAR Collaborative) Program. It is commonly used as a check variety in INGER nurseries. The yield of Sabita in national trials from 1988 to 2005 averaged 3 t ha^{-1}. But it has shortcomings—susceptibility to lodging and bacterial blight. There is a need to develop an alternative to Sabita, one with higher yield potential.

CN1231-11-7 is an advanced breeding line selected from the F_2 of IR73232 (IR57519-PMI-4-1-1-3-1/CN 846-6-6//IR58910-202-1-3-2-2). These breeding materials were originally received from IRRI as F_2 pedigree lines in 1998 and were exposed to typical rainfed lowland growing conditions for generation advance, assessment, and selection, following the method of Mallik et al (2002) at RRS. In 2000, seven F_4 lines of IR73232 were sent to CRRI at Pusa, North Lakhimpur, and Masodha for further selection. F_5 lines were selected at different locations in 2000: 10 at CRRI, 24 at North Lakhimpur, 7 at Masodha, and 6 at Chinsurah. CN1231-11-7, one of the six selections made at RRS, was nominated to the national trial in 2002. It was designated as IET17792.

The entry ranked first (4.96 t ha^{-1}) in terms of overall mean yield in IVT SDW (Table 1). In the 2003 AVT SDW, CN1231-11-7 registered 20% and 31% higher

Table 1. Performance of CN1231-11-7 in national trials, 2002-04.[a]

Location/trial	Yield (t ha^{-1})					Max water
	CN1231-11-7	Sabita	Purnendu	Expt. mean	CD (0.05)	depth (cm)
	Initial variety trial—semideepwater 2002 (47 entries)					
Bhubaneshwar, Orissa	3.7 (4)	2.4	2.2	2.6	0.5	NA
CRRI, Cuttack, Orissa	4.3 (9)	4.1	4.6	3.2	1.0	38
Pusa, Bihar	7.0	6.7	6.2	5.8	2.6	35
Chinsurah, West Bengal	4.0	3.3	3.5	3.2	NS	64
Gosaba, West Bengal	5.0 (4)	3.6	3.2	3.5	1.6	40
Canning, West Bengal	4.2 (4)	3.3	2.9	3.1	0.3	40
Coochbehar, West Bengal	5.3 (2)	4.6	3.1	4.0	0.9	72
Faizabad, Uttar Pradesh	5.0 (1)	3.5	3.3	3.6	0.5	42
Aduthurai, Tamil Nadu	5.6 (7)	2.3	3.1	3.7	0.3	80
Mudigere, Karnataka	6.6 (5)	7.1	5.6	4.9	1.4	5
Gerua, Assam	3.9	3.0	2.3	3.2	1.6	NA
Mean	4.96	3.99	3.34			
	Advanced variety trial 1—semideepwater 2003 (13 entries)					
Bhubaneshwar, Orissa	3.1	1.7	1.8	2.9	0.6	NA
Pusa, Bihar	3.2	2.7	3.1	3.4	0.6	165
Faizabad, Uttar Pradesh	2.4	3.9	2.4	1.2	0.5	NA
Gerua, Assam	5.5	4.6	5.3	5.5	0.3	NA
Maruteru, Andhra Pradesh	4.8	2.9	1.9	3.4	0.5	NA
Mean	3.8	3.16	2.9			
	Shuttle breeding replicated yield trial 2004 (19 entries)					
Chinsurah, West Bengal (N)[b]	5.4 (3)	2.5		4.3	0.46	<40 cm
Chinsurah, West Bengal (D)[c]	3.0	2.3		3.2	0.55	<40 cm
Masodha, Uttar Pradesh (N)	3.6	3.6		5.2	0.80	<40 cm
Patna, Bihar (N)	4.2	3.5		4.2	1.00	<40 cm
Patna, Bihar (D)	3.0 (4)	2.9		2.5	2.70	<40 cm
Titabar, Assam (N)	3.5	2.6		3.9	0.56	<40 cm
Mean	3.78	2.9				
Chinsurah, West Bengal (N)	5.2 (1)	3.1		3.7	0.55	>40 cm
Chinsurah, West Bengal (D)	2.1 (4)	2.0		1.5	0.37	>40 cm
CRRI, Cuttack, Orissa (N)	2.9 (3)	3.1		1.5	0.31	>40 cm
CRRI, Cuttack, Orissa (D)	1.6 (4)	1.4		1.2	0.23	>40 cm
Motto, Orissa (N)	2.5	2.1		3.3	0.29	>40 cm
Motto, Orissa (D)	3.6	4.0		3.7	0.21	>40 cm
Mean	2.98	2.62				
Grand mean (28 locations)	3.88					

[a]Numbers in parentheses indicate ranking of the entry. NA = not available, NS = not significant. [b]N = normal planting. [c]D = delayed planting.

yield than national check Sabita and regional check Purnendu, respectively. In the 2004 shuttle breeding replicated yield trial (RYT), it yielded 3.78 t ha^{-1} under a semishallow ecosystem (<40 cm water) and 2.98 t ha^{-1} under a deepwater ecosystem (>40 cm water). This was 30% and 14% higher than Sabita's yield.

On-farm mother trials with 10–12 promising entries selected from the AVT and RYT were conducted in farmers' fields—two in 2003, four in 2004, and 11 in 2005. In these trials, the researchers planned, made the field layout, and implemented the experiments. But field management was carried out entirely by the farmers. During 2003, CN1231-11-7 was on a par with Salivahana, a national check for AVT-Late at Bhartargachi, but it registered a 30% higher yield at Bora (Table 2).

A farmers' preference study conducted in both locations showed 4 of 13 farmers in Bora and 5 of 10 farmers in Bhartargachi preferring CN1231-11-7 over other entries. In 2004, CN1231-11-7 had 26–61% higher yield than the checks. In 2005, of 11 locations, the highest yield increase was observed in two locations in Orissa (89% and 65% higher yield than Sabita), whereas no yield advantage was noted at two sites in Orissa and West Bengal. The highest yield of 5.6 t ha^{-1} was recorded at Kirtinagar, West Bengal.

On-farm baby trials with one or two entries were conducted in eight farmers' fields in 2005. Seven of these farmers recorded yields higher than those of their own check varieties. Six farmers planned to grow CN1231-11-7 in 2006 and four farmers had already

Table 2. Performance of CN1231-11-7 (IET17792) in on-farm mother and baby trials 2003-05.

Year/location/trial	Yield (t ha^{-1}) CN1231-11-7	Yield (t ha^{-1}) Check	Check variety	CD (0.05) (%)	Increase
On-farm mother trials 2003					
Bhartargachi, Hooghly, West Bengal	4.4	4.4	Salivahana	0.24	Nil
Bora, 24 Pgs (N), West Bengal	3.5	2.7	Salivahana	0.31	30
Mean (2 locations)	3.9	3.5			
2004					
Gotu, Hooghly, West Bengal	4.5	2.8	Salivahana	0.46	61
Kanagarh, Hooghly, West Bengal	4.9	3.9	Salivahana	0.67	26
Kirtinagar, Hooghly, West Bengal	3.9	3.1	Salivahana	0.40	26
Bora, 24 Pgs (N) , West Bengal	4.5	2.9	Salivahana	0.52	55
Mean (4 locations)	4.4	3.2			
2005					
Gotu, Hooghly, West Bengal	4.3	4.0	Bhudeb	0.34	8
Kirtinagar, Hooghly, West Bengal	5.6	4.7	Bhudeb	0.43	19
Chinsurah, Hooghly, West Bengal	5.2	5.8	Bhudeb	0.25	Nil
Kaudikol, Orissa	2.7	2.7	Sabita	0.38	Nil
Arilo, Orissa	3.9	2.3	Sabita	0.69	65
CRRI, Orissa	4.2	2.2	Sabita	0.54	89
Bhubaneshwar, OUAT, Orissa	2.8	2.0	Sabita	0.36	37
RARS, Garumuria, Assam	2.8	2.2	Sabita	0.18	27
Garumuriagaon, Assam	4.1	3.4	Sabita	0.24	21
Baichagaon, Assam	3.2	2.5	Sabita	0.31	28
Mean (11 locations)	3.9	3.2			
On-farm baby trial, 2005, West Bengal				Area[b]	
Pandua, Hooghly	5.2	4.5	Bullet	6	16
Salboni, Midnapur	5.1	4.0	Swarna	10	28
Rampur, Burdwan	3.5	4.2	Bullet	10	Nil
Chanditala, Hooghly	4.5	3.9	Swarna	20	15
Sadya, Burdwan	5.2	4.9	Bullet	20	6
Mondalai, Hooghly	4.8	4.5	Ranjit	20	7
Maheshpur, Hooghly	4.9	4.6	Bullet	10	7
Uachai, Hooghly	5.0	4.3	Swarna	20	16
Mean (8 locations)	4.8	4.4			
Grand mean (25 locations)	4.2				

[a]Mean of two locations. [b]Area planted in khathas for CN1231-11-7 by individual farmers (1 ha = 150 khathas).

Table 3. Grain and quality characteristics of CN1231-11-7 and Sabita.

Trait	CN1231-11-7	Sabita
Grains panicle^{-1} (no.)	170	130
Panicle length (cm)	25	26
Grain length (mm)	9.6	10.9
Grain breadth (mm)	2.4	2.9
Grain L/B	4.0	3.7
Test weight (g)	25.0	31.0
Hulling (%)	78.0	79.0
Milling (%)	71.0	69.0
Head rice recovery (%)	63.0	56.0
Kernel length (mm)	7.4	7.3
Kernel breadth (mm)	2.2	2.2
Kernel L/B	3.4	3.4
Grain type	Long slender	Long slender
Chalkiness	0	Occasionally chalky
Kernel length after cooking (mm)	11.3	11.5
Volume expansion ratio	3.9	4.0
Elongation ratio	1.6	1.6
Alkali value	5.5	5.0
Water uptake (mL)	245	180
Amylose (%)	23.4	23.7
Selling price per bag (60 kg) as of January 2006[a]	Rs 350	Rs 320
Taste of cooked rice (15 farmers)	Good	OK

[a]US$1=Rs 45.

distributed its seeds to 20 of their farmer neighbors. The benefit-cost ratio (B/C) obtained for CN1231-11-7 was 2.78; that for Sabita was 1.82. The farmers said they chose CN1231-11-7 because of its erect, nonlodging plant type, low incidence of pests and diseases, higher market price (price for 60-kg paddy is Rs 350 for CN 1231-11-7, Rs 290 for Swarna, Rs 260 for Bullet, Rs 280 for Salivahana, Rs 310 for Ranjit, and Rs 320 for Sabita as of early 2006), higher head rice recovery, and higher net return.

CN1231-11-7 is strictly photoperiod-sensitive and flowers between 25 and 30 October at RRS (22°52'N, 88°24'E). It is erect, 130–140 cm tall, and lodging-resistant. The panicle has 13–14 primary branches and 40–45 secondary branches with 180–190 spikelets, 160–170 of which develop into full grains. The grains are long and slender; head rice recovery is 63% (Table 3). Seed dormancy lasts for 3 mo, preventing viviparous germination.

CN1231-11-7 has a wide and diverse genetic base, having parents such as Khao Dawk Mali, Benong, Pa Chiam, Bhasamanik, Fortuna, FR13A, Arikarai, Milek Kunning, IR36, and Mudgo. This genetic background provided wider adaptability to varying growing conditions, better tolerance for pests and diseases, superior grain quality, and higher returns to the resource-poor farmers in this ecosystem. The variety at present is in the pre-release stage and would be ideal replacements for Sabita and other varieties in the rainfed lowlands.

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New rice variety Shusk Samrat for drought-prone areas of eastern Uttar Pradesh, Bihar, and Chhattisgarh, India

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About 5 million ha in India is rainfed upland, most of it drought-prone. Countrywise, India has the biggest cultivated area, followed by Brazil (2.4 million ha) and Indonesia (1.2 million ha). Average productivity is less than 1.5 t ha^{-1}. In India, early-maturing (100–105 d) rice varieties are predominantly grown in such areas, with rice-wheat, rice-maize, and rice-tobacco as the most popular cropping patterns used. NDR1045-2 (Shusk Samrat), a variety with tolerance for low-fertility stress and responsive to favorable conditions, was recommended by the Varietal Identification Committee of the Indian Council of Agricultural Research in 2005 for direct-seeded, drought-prone areas of eastern Uttar Pradesh, Bihar, and Chhattisgarh.

Shusk Samrat (IET17458) is developed from C1064-5/Kalkari//IR54 using the pedigree breeding method. This entry consistently gave excellent yields over national, regional, and local check varieties in national coordinated initial and advanced varietal trials in the 2001-03 wet seasons (WS) (Table 1). Its yield potential is 3.0–3.5 t ha^{-1}. This variety was registered with the National Bureau of Plant Genetic Resources in August 2005.

Table 1. Yield (kg ha^{-1}) of Shusk Samrat in national coordinated variety trials, 2001-03.

Year of testing	Shusk Samrat	Annada (national check)	Narendra 97 (regional check)	Narendra 118 (local check)
2001 WS (7 locations)	3,062(1)	1,957	2,246	1,654
2002 WS (9 locations)	2,755(2)	1,973	2,176	2,347(7)
2003 WS (11 locations)	3,127(6)	2,805	2,627	2,723
Weighted mean	2,986	2,308	2,378	2,324
Percentage increase/decrease over checks				
2001 WS		+56.5	+36.33	+85.12
2002 WS		+39.6	+26.60	+17.38
2003 WS		+11.5	+19.03	+14.83
Mean		29.4	25.6	28.5
Frequency in the top group (pooled over 3 y)	21/27	7/27	6/27	6/27

Shusk Samrat is semidwarf (95–100 cm), with 6-8 panicle-bearing tillers plant^{-1} (Table 2). Maturity duration is 100–105 d. Grain type is long bold and head rice recovery is 62.4%. It is moderately resistant to major insects and pests such as stem borers, gall midge, leaffolders, and whorl maggots. It is also resistant to sheath rot and brown spot and moderately resistant to sheath blight.

The new variety is a good alternative to high-yielding rice varieties Narendra 118, Narendra 97, Annada, Vandana, Khandagiri, and Prabhat because of its early maturity, semidwarf stature, high yielding ability, and good grain quality. Further, its short growth duration and high harvest index give better opportunities for double cropping in drought-prone areas of eastern India. Shusk Samrat performed well under aerobic conditions too.

Table 2. Salient characteristics of Shusk Samrat.

Plant height	95–100 cm	Kernel length (mm)	6.24
Plant type	Semidwarf	Kernel breadth (mm)	2.20
Tillers plant^{-1} (no.)	6–8	Length/breadth	2.83
Panicles m^{-2} (no.)	270–310	Grain type	Long/bold
Flowering duration	75–80	Kernel color	White
Seed-to-seed duration	100–105 d	Milling recovery (%)	68.8
Panicle type	Compact	Head rice recovery (%)	62.4
Panicle exsertion	Well exserted	Alkali value	4.0
Awning	Awnless	Amylose content	27.5
Apiculus	Straw	Threshability	Easy
1,000 grain weight (g)	21.6	Yield (t ha^{-1})	3.0–3.5

Use of resistant varieties and organic nutrients to manage yellow stem borer in rice

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Stem borers are destructive pests of rice, attacking all stages of the rice plant from seedling to maturity. In India, yellow stem borer (YSB) caused 1–19% yield loss in early planted rice and 38–80% yield loss in late-planted rice (Catindig and Heong 2003). The use of resistant varieties is one important technique in integrated pest management (Dilawari and Dhaliwal 1993). Although resistant cultivars have been developed and planted over large areas, they cannot hold the growth of the insect population at levels below the economic threshold because of various other stresses during cultivation (Panda and Khush 1995).

The important components that form the organic bases for pest management are organic manure, biofertilizers, and soil amendments such as fly ash (Chandramani 2003). Until now, not much attention has been given to studying the impact of using resistant varieties, along with application of nutrients from organic sources, on managing insect pests of rice. A field experiment was conducted from October 2004 to January 2005 at ACRI. A randomized block design with nine treatments and three replications was used. All agronomic practices were followed uniformly in all plots (5 × 4 m^2). In each plot, bunds were strengthened to avoid leaching losses. In addition, plots where organic nutrients were applied were separated by a distance of 1 m. A 2-m isolation distance was maintained between plots with organic nutrients and those with inorganic fertilizers. The resistant varieties studied were TKM6, IR36, and a check, MDU5. The organic nutrients used were farmyard manure (FYM), biofertilizers, lignite fly ash, and neem cake.

The different treatments were T_1: TKM6 + FYM + biofertilizers + lignite fly ash + neem cake; T_2: TKM6 + NPK alone (100-50-50 kg NPK ha^{-1}); T_3: TKM6 alone; T_4: IR36 + FYM + biofertilizers + lignite fly ash + neem cake; T_5: IR36 + NPK alone (100-50-50 kg NPK ha^{-1}); T_6: IR36 alone; T_7: MDU 5 + FYM + biofertilizers + lignite fly ash + neem cake; T_8: MDU5 + NPK alone (100-50-50 kg NPK ha^{-1}); and T_9: MDU5 alone.

The concentrations used were as follows: FYM, 12.5 t ha^{-1} as basal; biofertilizers (*Azospirillum* + phosphobacterium + silica-solubilizing bacteria [SSB], each at 2 kg ha^{-1} as basal); lignite fly ash, 250 kg as basal and 250 kg in two equal splits at 30-d intervals; and neem cake, 125 kg ha^{-1} as basal, and 125 kg ha^{-1} in three equal splits at 20-d intervals.

In each treatment during the vegetative phase, the total number of tillers and number of deadhearts in 10 hills were recorded and expressed as percent deadhearts. At the reproductive phase, the total number of productive tillers and number of whiteheads were recorded from 10 hills in each treatment and expressed as percent whiteheads. Data collected from different field and pot culture experiments were statistically analyzed using randomized and completely randomized block designs, respectively. The percentage values were subjected to angular transformation. Treatment means were compared by Duncan's multiple range test. In addition, rice stem samples were collected from the field 45 d after transplanting (DAT) to estimate silicon and phenol content of the plant.

The percent deadhearts recorded at 30 and 45 DAT and the percent whiteheads at 70 DAT were significantly different (Table 1). Deadhearts ranged from 0.51% to 12.04% at 30 DAT. TKM6 treated with FYM, *Azospirillum*, phosphobacterium, SSB, lignite fly ash, and neem cake recorded significantly less deadheart incidence (0.51%) with a corresponding reduction of 95.8% and 83.8% over MDU5 + NPK (inorganic) and TKM6 + NPK (inorganic), respectively. The same trend was observed at 45 DAT. Of the nine combinations tested, TKM6 given organic nutrients recorded the lowest whitehead incidence (0.97%) as against that of MDU5 + NPK (inorganic) (6.9%).

Varietal resistance, along with organic nutrients, might have arrested YSB infestation. Because of its consistent performance, TKM6 was identified and extensively

Table 1. Effect of using resistant varieties with organic sources of nutrients on incidence of yellow stem borer in rice.[a]

Treatment[b]	Days after transplanting[c]					
	30		45		70	
	% deadhearts	% reduction over NPK	% deadhearts	% reduction over NPK	% whiteheads	% reduction over NPK
TKM6 + FYM + NC + Azos + Phos + SSB + LFA	0.51 (2.55) a	95.80 (6.91)a	1.44 (4.71) a	89.97	0.97	85.95
TKM6 + NPK (inorganic form)	3.14 (10.22) bc	73.89	3.63 (10.61)bc	74.80	2.09 (8.20)b	69.63
TKM6 alone	2.82 (7.65) ab	76.59	3.36 (10.55)ab	76.68	1.68 (7.45)ab	75.61
IR36 + FYM + NC + Azos + Phos + SSB + LFA	6.12 (14.33) cd	49.12	7.16 (15.49)cd	50.31	3.06 (10.09)bc	55.54
IR36 + NPK (inorganic form)	10.19 (18.55) de	15.36	11.28 (19.60)de	21.69	6.20 (14.38)d	10.02
IR36 alone	9.78 (18.18) de	18.74	10.45 (18.85)de	27.48	5.86 (13.89)d	14.96
MDU5 + FYM + NC + Azos + Phos + SSB + LFA	7.34 (15.68) de	38.99	7.41 (15.33)cd	48.53	4.44 (12.04)cd	35.50
MDU5 alone	11.62 (19.93) e	3.47	14.19 (22.26)e	1.53	6.45 (15.21)d	6.35
MDU5 + NPK (inorganic form)	12.04 (20.27) e	–	14.41 (22.12)e	–	6.89 (14.68)d	–

[a]In a column, means followed by the same letter are not significantly different at $P = 0.05$ as per DMRT. [b]FYM = farmyard manure, NC = neem cake, LFA = lignite fly ash, Azos = *Azospirillum*, Phos = phosphobacterium, SSB = silicate-solubilizing bacteria. Values in parentheses are arcsine transformations. [c]Mean of three replications.

used as a resistance donor in several breeding programs (Roy et al 1969). Saroja et al (1993) confirmed the high level of resistance in TKM6, which is less susceptible at both vegetative and heading stages. This is attributed to its narrow lumen, resulting in less susceptibility to borer infestation. The increased Si, phenol, and tannin contents in TKM6 after treatment with organic fertilizers may have induced resistance by way of antibiosis. This supported the findings of Chandramani (2003), who found that application of FYM, biofertilizers (either with or without lignite fly ash), and neem cake applied in splits was highly effective in reducing YSB damage in all growth stages of MDU5. The results from this study indicated that application of *Azospirillum* would have favorably activated the phenyl ammonia lyase enzyme implicated in the biosynthesis of phenolics, resulting in increased plant phenolics that prevent damage (Mohan et al 1988). The low incidence of YSB might be attributed to the high Si content in lignite fly ash and the release of Si by SSB. This confirms the finding that higher Si content resulted in lower incidence of deadhearts and higher insect mortality (Subbarao and Perraju 1976). Although TKM6 has a high level of resistance to YSB, the use of soil amendments can create an unfavorable environment, inducing resistance through antibiosis or feeding inhibition. This resistance was mainly due to the higher amount of phenol (7.80 mg g^{-1} of tissue) and Si content (6.5%) in the rice stem (Table 2).

Table 2. Influence of promising sources of resistance with organic sources of nutrients on the biochemical constituents in the plant.[a]

Treatment	Total phenol (mg g^{-1})[a]	Silica content (%)[b]
TKM6 + FYM + NC + Azos + Phos + SSB + LFA	7.80 a	6.50 a
TKM6 + NPK (inorganic form)	6.10 b	5.53 a
TKM6 alone	6.03 b	5.27 ab
IR36 + FYM + NC + Azos + Phos + SSB + LFA	5.60 c	5.07 b
IR36 + NPK (inorganic form)	3.63 d	4.53 c
IR36 alone	3.77 d	4.23 c
MDU5 + FYM + NC + Azos + Phos + SSB + LFA	2.60 e	3.70 d
MDU5 alone	2.50 e	2.33 e
MDU5 + NPK (inorganic form)	2.40 e	2.30 e

[a]In a column, means followed by the same letter are not significantly different at $P = 0.05$ as per DMRT. [b]Mean of three replications.

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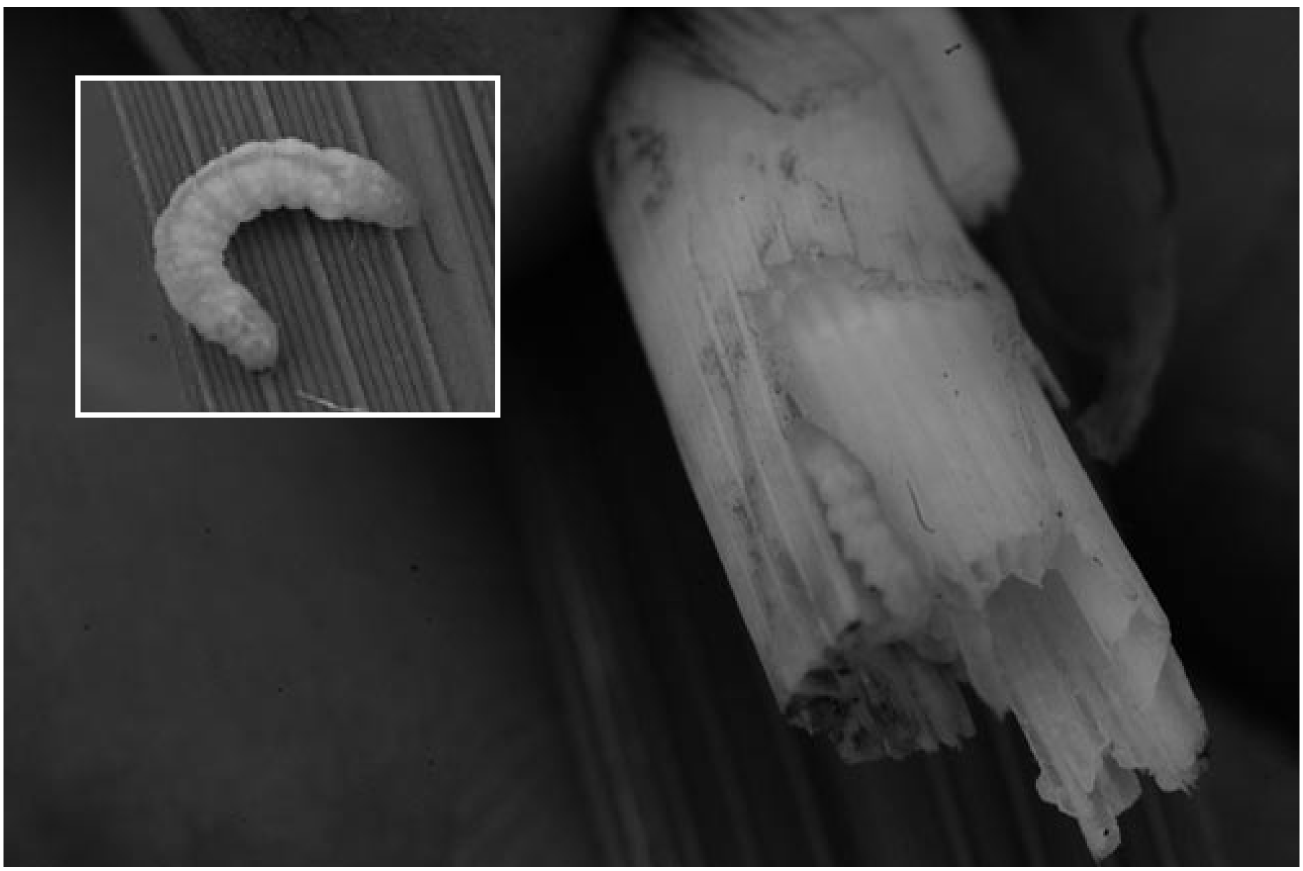

Seed priming enhances emergence, yield, and quality of direct-seeded rice

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Rice transplanting requires a large amount of labor, which often results in a labor shortage and increasing labor costs at critical times. In addition, under a changing socioeconomic environment, workers are not available or are reluctant to undertake tedious operations such as transplanting seedlings. Alternate methods that require less labor and less water without sacrificing productivity are needed. A fundamental approach to reducing water inputs in rice is to grow the crop like an irrigated upland crop such as wheat or maize. Considering water availability and labor costs, direct seeding is an appropriate alternative to traditional transplanting. However, poor germination, uneven crop stand, and high weed infestation are the main constraints to its adoption (Balasubramanian and Hill 2002).

Improved seed invigoration techniques are known to reduce emergence time, accomplish uniform emergence, and give better crop stand in many horticultural and field crops. These include hydropriming, osmoconditioning, osmohardening, hardening, hormonal priming, and soaking before sowing (Ashraf and Foolad 2005). Farooq et al (2006) recently introduced a new technique for rice seed invigoration that successfully integrated hardening and osmoconditioning. The process was named osmohardening (Farooq et al 2006). Osmohardening in CaCl2 (ψ_s – 1.25 MPa) solution was found to be better for vigor enhancement than other priming strategies.

Although seed priming techniques have been found effective for better germination and seedling establishment in rice under controlled conditions (Basra et al 2005, Farooq et al 2006), and although some success in enhancing the performance of direct-seeded rice has been reported (Du and Tuong 2002), no comprehensive study has yet been done to evaluate the response to a wide range of seed invigoration techniques to enhance germination, yield, and quality of harvested paddy. This study aimed to evaluate the effectiveness of a range of seed priming techniques in improving germination, yield, and quality of direct-seeded rice.

Coarse (KS 282) and fine rice (Super basmati) seeds were used in the study. The moisture content of the seed was around 8%. The 2004-05 study was conducted in 6.5 × 4.5-m plots. The experiment was laid out in a randomized complete block design with three replications.

The seed invigoration treatments (Basra et al 2005,Farooq et al 2006) were 1) pregermination, a traditional practice of soaking seeds in water for 24 h, then placing them between two layers of saturated gunny bags until radicles appear (chitting stage); 2) hydropriming, soaking seeds in aerated distilled water for 48 h; 3) hardening, alternate soaking of seeds in tap water at 27 ± 3 °C for 24 h and drying (one cycle); 4,5) osmohardening, similar to hardening but in the presence of $CaCl_2$ or KCl solution with ψ_s = –1.25 MPa (one cycle); and 6) ascorbate priming, soaking seeds in 10 mg L^{-1} aerated solution of ascorbic acid for 48 h. The control consisted of fresh seeds that received no treatment. Primed seeds were given three washings with water and redried near the original moisture (~8%) under forced air at 27 ± 3 °C (except for pregermination). These seeds were put in polythene bags and stored in a refrigerator at 5 ± 2 °C until they were used.

Field soil was sandy clay loam, with pH 8.1, electrical conductivity of 0.30 dS m^{-1}, and 0.75% organic matter. Land was plowed five times to prepare the required seedbed. The fertilizers applied were urea (46%), single superphosphate (18% P_2O_5), sulphate of potash (50% K_2O), and $ZnSO_4$ (35% Zn). Based on a soil analysis report, 150 kg N, 39.6 kg P, 62.2 kg K, and 10 kg Zn ha^{-1} were applied to fine rice; 120 kg N, 33 kg P, 62.2 kg K, and 10 kg Zn ha^{-1} were applied to coarse rice. The whole quantity of P, K, and Zn and half of N were applied before sowing as a basal dose. The remaining half dose of N was applied in two equal splits—at tillering and at panicle initiation. Seeds were drilled in 22-cm rows with a single-row hand drill at 65 kg ha^{-1} on 1 Jun 2004. Irrigation was applied when soil moisture was slightly below field capacity.

To control weeds, a mixture of ethoxy sulphuran and phenoxy-prop-p-ethyl (200 g and 370 mL ha^{-1}, respectively) was applied 20 d after sowing in saturated soil. In all, 10 irrigations were applied during the crop growth period. Irrigation was stopped 10 d before harvest.

The number of days to 50% emergence (E50) was computed as described by Farooq et al (2006) and final emergence percentage (FEP) was calculated when a constant stand had been achieved. Yield components and spikelet and kernel characteristics were recorded at full maturity and the crop was harvested when fully ripe to determine paddy yield. Kernel proteins from fresh kernels were determined from total N estimated by the micro-Kjeldahl method multiplied by a factor (5.95). Kernel water absorption ratio was taken as the ratio of weight of cooked rice to that of raw rice.

Seed priming treatments significantly affected seedling emergence in both rice types. In coarse rice, the lowest E50 and highest FEP values were obtained from seeds osmohardened with KCl, followed by those with $CaCl_2$, hardening, and ascorbate priming, whereas the highest E50 and lowest FEP were obtained with pregerminated seeds and the control (Table 1). The maximum number of tillers, 1,000-kernel weight, and kernel yield were recorded in seeds osmohardened with KCl. Similar values of tiller number were observed with hydropriming, osmohardening with $CaCl_2$, hardening, and ascorbate priming and 1,000-kernel weight was the same as that noted in the hardening treatment. The least 1,000-kernel weight and kernel yield were recorded from pregerminated seeds; the other treatments gave similar results, except for hardening (1,000-kernel weight) and control and hydropriming (kernel yield) (Table 1). However, the minimum number of tillers was noted in control seeds, followed by pregerminated seeds. The effect of seed priming on the number of branches per panicle was not significant (Table 1). No remarkable differences in kernel length and width were evident (Table 2). All seed treatments, except control and pregermination, resulted in increased kernel protein. The minimum kernel water absorption ratio was noted in pregerminated seeds, followed by control, and those exposed to hydropriming. However, the last two attributes were maximum in the osmohardening treatment with KCl (Table 2).

In fine rice, the lowest E50 and the highest FEP were noted in seeds osmohardened with $CaCl_2$. Hardening had the same FEP, whereas the highest E50 and lowest FEP were seen in pregerminated and control seeds (Table 1). Seeds osmohardened with $CaCl_2$ had the highest number of tillers, 1000-kernel weight, and kernel yield, which was also observed in seeds exposed to hydropriming, osmohardening with KCl, hardening, and ascorbate priming (kernel yield), and hardening (1,000-kernel weight). Minimum values of these attributes were

Table 1. Effects of seed priming on germination and yield of direct-seeded coarse and fine rice.[a]

Treatment	Days to 50% emergence	Final emergence (%)	Tillers (no. m^{-2})	Branches $panicle^{-1}$ (no.)	1,000-kernel weight (g)	Kernel yield (t ha^{-1})
			Coarse rice			
Pregermination	5.66 a	79.0 d	675.7 b	21.3	15.33 b	2.61 de
Hydropriming	4.32 ab	85.0 b	737.7 a	22.0	16.67 b	2.78 d
Osmohardening (KCl)	4.00 b	87.7 a	738.5.a	22.0	19.00 a	3.23 a
Osmohardening ($CaCl_2$)	4.30 b	87.7 a	716.0 a	24.3	16.33 b	3.11 b
Ascorbate priming	4.80 ab	82.0 c	705.7 a	22.9	16.67 b	3.01 c
Hardening	4.39 b	84.0 bc	713.3 a	24.0	17.00 ab	3.03 c
Control	5.35 a	79.7 d	623.3 c	21.2	16.33 b	2.71 d
LSD (0.05)	0.93	2.1	31.21	ns	2.00	0.091
			Fine rice			
Pregermination	5.56 a	47.0 e	526.3 d	22.0	14.33 c	2.01 b
Hydropriming	4.03 c	63.0 bc	608.3 c	21.0	15.33 b	2.71 a
Osmohardening (KCl)	4.55 c	68.0 b	625.3 b	22.7	15.67 b	2.76 a
Osmohardening ($CaCl_2$)	3.54 d	76.7 a	684.7 a	23.7	17.00 a	2.96 a
Ascorbate priming	5.20 b	65.0 b	608.3 c	21.7	14.00 c	2.63 a
Hardening	4.49 c	76.0 a	640.3 b	22.0	16.33 a	2.75 a
Control	5.57 a	56.0 d	517.3 d	21.7	14.67 c	2.11 b
LSD (0.05)	0.28	4.6	16.11	ns	0.96	0.061

[a]Means followed by the same letter in a column do not differ significantly at $P = 0.05$.

observed in pregerminated and control seeds (Table 1). However, the effect of seed priming on the number of branches per panicle was not significant (Table 1). Also, seed priming did not significantly affect kernel length and width (Table 2). All seed treatments resulted in much improved kernel protein and kernel water absorption ratio compared with the control (untreated) (except pregermination for kernel proteins). The highest values were obtained from seeds osmohardened with $CaCl_2$ (Table 2).

This study revealed that seed priming techniques promoted germination, yield, and grain quality of rice. Osmohardening with KCl and $CaCl_2$ gave the most pronounced effect in enhancing emergence and yield (Table 1). In addition to successful hydration during priming, these salts proved beneficial because of their role in enzyme activation, in particular, of hydrolases. This is plausible as a positive correlation exists between seed vigor and field performance of rice (Du and Tuong 2002). Furthermore, seed priming produced more vigorous, faster growing, and uniform seedlings (Farooq et al 2006). The poor performance of pregerminated seeds may be due to the damage done on the protruded radicles during sowing. A field evaluation of seed priming strategies was made in terms of kernel yield and quality characteristics. Improved kernel yield as a result of seed priming is possibly due to improvement in yield-contributing factors (Table 1). The better kernel water absorption ratio may be explained by improved kernel proteins (Table 2), which are hygroscopic in nature.

These findings strongly suggest the practicability of seed priming techniques in direct-seeded rice, particularly with KCl and $CaCl_2$ osmohardening in coarse and fine rice, respectively.

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Table 2. Effect of seed priming on kernel quality in direct-seeded coarse and fine rice.[a]

Treatment	Kernel length (mm)	Kernel width (mm)	Kernel protein (%)	Kernel water absorption ratio
		Coarse rice		
Pregermination	5.31	1.54	6.50 d	3.13 d
Hydropriming	5.31	1.53	6.90 c	3.33 c
Osmohardening (KCl)	5.39	1.54	7.39 a	3.67 a
Osmohardening ($CaCl_2$)	5.63	1.52	7.21 ab	3.58 ab
Ascorbate Priming	5.43	1.51	7.01 bc	3.55 b
Hardening	5.66	1.55	7.16 ab	3.60 ab
Control	5.58	1.55	6.61 d	3.28 c
LSD (0.05)	ns	ns	0.2639	0.09
		Fine rice		
Pregermination	6.24	1.47	7.60 c	4.12 bc
Hydropriming	6.37	1.45	7.94 b	4.21 b
Osmohardening (KCl)	6.31	1.46	8.00 b	4.37 ab
Osmohardening ($CaCl_2$)	6.34	1.44	8.16 a	4.46 a
Ascorbate Priming	6.36	1.45	7.91 b	4.26 b
Hardening	6.51	1.43	7.98 b	4.30 b
Control	6.11	1.46	7.62 c	3.99 d
LSD (0.05)	ns	ns	0.159	0.096

[a]Means following the same letter in a column do not differ significantly at P = 0.05.

Crop intensification for sustainable crop productivity and soil fertility under favorable rainfed lowlands

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Crop intensification has immense prospects to overcome uncertainties in rice farming under rainfed lowland conditions (Ingram 1995) while ensuring sustainable crop productivity and soil fertility too. An on-farm study from 2002 to 2004 explored the feasibility of accommodating a preceding crop, jute (*Corchorus capsularis /olitorius*), and a succeeding crop, green gram (*Phaseolus radiatus*), in sequence with rice (*Oryza sativa*) in farmers' fields. The experimental site was the predominantly jute-growing belt under favorable rainfed lowlands at Cuttack and Kendrapara districts in Orissa, India. Although jute-rice is the existing cropping system, farmers could not get adequate remuneration from this system because of a lack of promising varieties. The productivity of local varieties is not only very poor; it is also inconsistent. Farmers barely grow any crop after rice. Besides evaluating the performance of improved varieties in this system, the feasibility of growing green gram was also studied. The objectives were to augment total production of this system (by using 300% cropping intensity) and to ensure sustainable soil fertility. The soil near the river basin is sandy clay loam. Available N, P, and K were 187.23, 23.83, and 158.83 kg ha^{-1}.

Improved jute varieties Subala (*C. olitorius*) and Sonali (*C. capsularis*) were sown along with a local variety during the first week of May and harvested in mid-August. Thereafter, improved rice varieties Durga (tall, long duration) and Gayatri (semi tall, medium duration) were transplanted using aged nursery seedlings (60 d) along with a local variety. These were harvested in mid-December. Delayed planting, even up to the first week of September using aged seedlings, was reported to produce reasonable yield (CRRI 2003). Green gram cultivars PDM54 and Pusa 105 were sown for comparison under residual soil moisture and nutrient, following rice, during the first week of January and were harvested in mid-March. The NPK requirements of jute and rice were estimated using the soil test crop response technique. For jute, 40-30-30 kg NPK ha^{-1} was applied; for rice, 60-30-30 kg NPK ha^{-1} was given. The N requirement was met with 75% N coming from organic sources (farmyard manure) and 25% from inorganic fertilizer sources. The experiment was laid out in a randomized complete block design in 10 farmers' fields (considered as 10 replications).

Monsoon starts in the second to third week of June, but a premonsoon rain from the last week of April to mid-May ensures germination and initial crop growth. The jute crop does not suffer from initial moisture stress. The soil remains saturated with moisture even up to the end of December. The residual moisture is sufficient to grow green gram until maturity.

Jute, rice, and green gram performed exceedingly well (Maclean et al 2002). The improved jute varieties consistently produced higher fiber (mean, 2.31–2.55 t ha^{-1}) than the local variety (1.22 t ha^{-1}, see table). Also, the grain yields of all improved

Performance of jute, rice, and green gram under rainfed lowland rice-based cropping system, 2002-04.

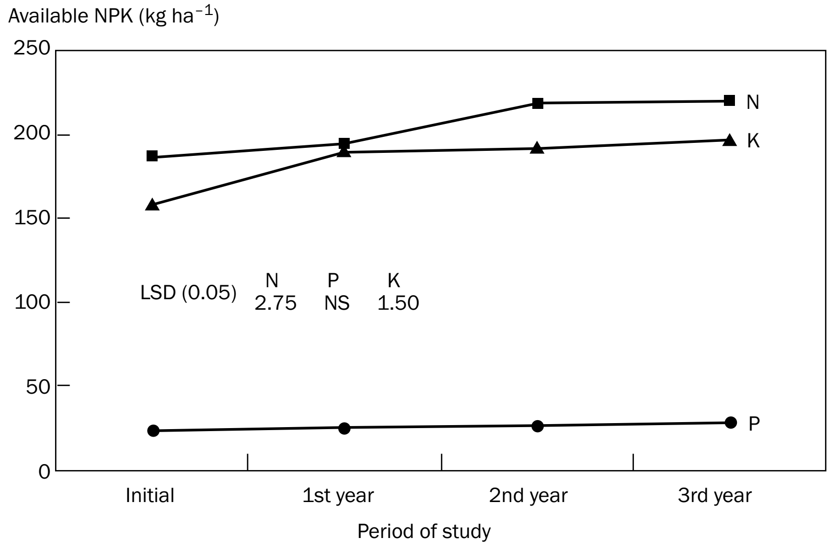
Crops in sequence	Yield (t ha^{-1})			Mean yield (t ha^{-1})	Net return (Rs ha^{-1})[a]	Benefit:cost
	2002	2003	2004			
Jute						
Sonali	2.20	2.81	2.63	2.55	11,550	0.70
Subala	2.10	2.54	2.29	2.31	15,752	1.31
Local	1.20	1.25	1.22	1.22	2,268	0.30
CD (P = 0.05)	0.10	0.25	0.22	0.17		
Rice						
Gayatri	3.47	3.65	3.52	3.55	9,535	1.33
Durga	3.20	3.40	3.35	3.32	9,454	1.25
Local	1.63	2.01	1.75	1.80	3,500	0.64
CD (P = 0.05)	0.17	0.17	0.15	0.14		
Green gram						
PDM54	10.09	12.65	12.45	12.00	13,000	1.60
Pusa 105	10.35	10.15	12.50	10.23	10,600	1.25
CD (P = 0.05)	ns	0.15	ns	0.17		

[a]Price of jute: *Capsularis*, Rs 8,000 t^{-1}, *Olitorius*, Rs 12,000 t^{-1}; price of rice: Gayatri, Rs 4000 t^{-1}, Durga, Rs 5,000 t^{-1}; price of green gram: Pusa 105 Rs 12,000 t^{-1}, PDM54, Rs 15,000 t^{-1}. 1US$ = Rs 46.

rice varieties remained consistently higher (mean, 3.32–3.55 t ha^{-1}) than that of the local variety (1.8 t ha^{-1}). The overall growth of green gram was satisfactory and PDM54 produced consistently high yield (mean, 1.2 t ha^{-1}).

Jute varieties Subala (Rs 15,752 ha^{-1}) and Sonali (Rs 11,550 ha^{-1}) fetched higher net returns than did the local variety (Rs 2,268 ha^{-1}). The net returns of rice varieties Gayatri (Rs 9,535 ha^{-1}) and Durga (Rs 9,454 ha^{-1}) were also higher than that of the local variety (Rs 3,500 ha^{-1}). PDM54 had a higher net return (Rs 13,000) than Pusa 105 (Rs 10,600) (CRRI 2001). Subsequently, the benefit-cost ratio of improved varieties was also higher than that of local varieties. Considering the rice equivalent yield of jute (5.4 t ha^{-1}) and green gram (3.3 t ha^{-1}), rice productivity could be estimated at 12.2 t ha^{-1} y^{-1}, much more than that achieved with monocropping (1.8 t ha^{-1}) and the conventional jute-rice system (4.2 t ha^{-1}).

The initial available N, P, and K status suggested that the soil was low in N and moderate in P and K. At the end of the first year, available soil N (195.3 kg ha^{-1}) and P (25.7 kg ha^{-1}) did not change much, whereas soil K (190.2 kg ha^{-1}) improved appreciably (see figure). At the end of the second year, soil N increased more (218.2 kg ha^{-1}) than P (26.4 kg ha^{-1}) and K (192.2 kg ha^{-1}). This was attributed to the additive effects of fallen jute leaves and green manure using green gram in the two previous years (Saha et al 2000). After the third year, there was noticeable improvement in NPK status—220.2, 27.5, and 197.1 kg ha^{-1}, respectively. These results implied that soil NPK status was enhanced progressively over the period of the experiment (Ghosh and Pati 2002). Available soil N, P, and K were enhanced by 17.6%, 15.4%, and 14.1%, respectively. Therefore, this study suggests that growing jute, rice, and green gram successively under favorable rainfed lowland conditions offers more advantages than following the traditional cropping system. Moreover, this system of crop intensification could improve soil fertility and thereby ensure sustainable crop and soil productivity (Ghosh and Jha 2003).



Soil NPK status under jute-rice-green gram cropping system under rainfed lowland conditions.

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Stably expressed QTLs for grain shape in rice grown in two Asian countries

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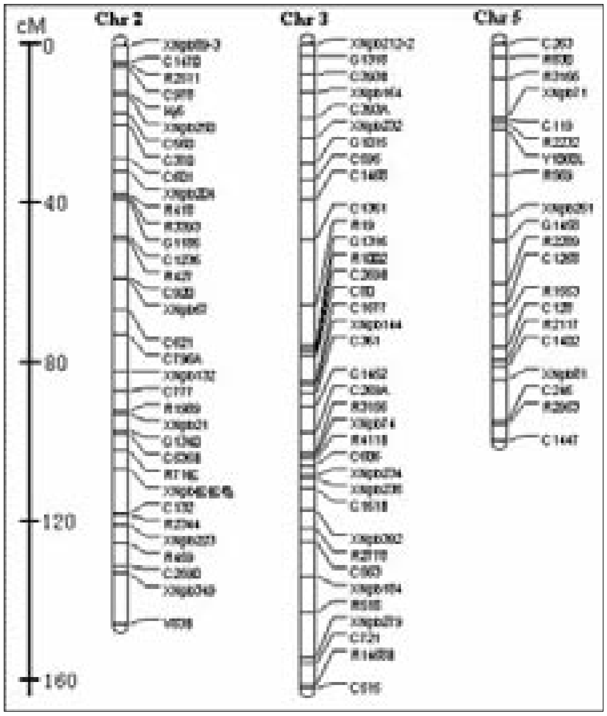
Grain shape is an important trait in rice as it can affect its yield, processing, and market value. One set of recombinant inbred lines (RILs) derived from the cross Asominori/IR24 (Tsunematsu et al 1996) was provided by Prof. A. Yoshimura of Kyushu University, Japan, along with molecular data, and was used to identify stably expressed quantitative trait loci (QTLs) for grain length (GL), grain width (GW), and grain length-width ratio (LWR) of rice varieties in two Asian countries (Japan and China). The seeds of RILs, along with parents Asominori and IR24, were sown on 15 May 2002 (Miyazaki, Japan) and on 15 May 2005 (Shanghai, China). After 30 d (Japan) and 25 d (China), seedlings were transplanted at the experimental farms of the Miyazaki University and the Shanghai Normal University (single seedling per hill, 10 × 10-cm spacing). The other management strategies followed local conventional methods. Well-ripened rice grains were selected to measure GL, GW, and LWR with replicates. In this study, composite interval mapping was used to identify the locations of QTLs (Zeng 1994) using Windows QTL Cartographer software (Wang et al 2005). A locus with LOD >3.0 in both countries was regarded as a stably expressed QTL. The additive effect and the percentage of variation explained by an individual QTL were also estimated.

Continuous variation and transgressive segregations of GL, GW, and LWR were observed in RI populations in both countries, indicating that grain shape was a quantitatively inherited trait. In addition, relationships for the same trait between different countries and the interrelationships among the three measured traits in Japan and China were significant at the 5% level (data not shown), suggesting that the expression of grain shape was relatively stable and that there existed a genetic relationship among the three traits. In the study, five stably expressed QTLs in both countries were detected and mapped to chromosomes 2, 3, and 5 (see table and figure). They were tentatively named qGL-3, qGW-2, qGW-5, qLWR-3, and qLWR-5. qGL-3 for GL was detected in both countries near C80 (chromosome 3) and explained 23.6% (Japan) and 21.4% (China) of total variance. qGW-2 near G1340 on chromosome 2 and qGW-5 near Y1060L on chromosome 5 were detected, accounting for 8.8–10.2% and 28.7–36.2% of total variance, respectively. Both qLWR-3 near G1316 on chromosome 3 and qLWR-5 near Y1060L on chromosome 5 were detected and could explain 17.7–22.4% and 27.0–28.4% of total variance. More interestingly, both qGW-5 and qLWR-5 might represent pleiotropy because they were located at the same genomic position. IR24 alleles in qGL-3, qLWR-3, and qLWR-5 increased the value of the trait, whereas IR24 alleles in qGW-2

Stably expressed QTLs for grain length (GL), grain width (GW), and grain length-width ratio (LWR) of rice varieties in two Asian countries.

Trait	QTL	Chromosome number	Interval markers[a]	Country	LOD value	Additive effect[b]	Variation[c] (%)
GL	qGL-3	3	*C80*-C1677	Japan	8.3	–0.68	23.6
				China	7.8	–0.36	21.4
GW	qGW-2	2	*G1340*-C535B	Japan	3.8	0.15	8.8
				China	3.3	0.08	10.2
	qGW-5	5	*Y1060L*-R569	Japan	11.2	0.31	36.6
				China	7.9	0.13	28.7
LWR	qGWR-3	3	R19-*G1316*	Japan	10.6	–0.19	22.4
				China	6.6	–0.17	17.7
	qGWR-5	5	*Y1060L*-R569	Japan	13.3	–0.20	27.0
				China	10.9	–0.21	28.4

[a]Markers in italics indicate the nearest marker linked to putative QTL. [b]Positive values indicate that Asominori alleles are in the direction of increasing values. [c]Variance explained by the QTL.



Chromosonal locations of stably expressed QTLs for grain length, grain width, and grain length-width ratio of rice varieties in two Asian countries.

and qGW5 decreased it. The five stably expressed QTLs for grain shape detected in this study and their tightly linked molecular markers will be more valuable in marker-assisted breeding to select rice varieties with suitable grain shape in Asian countries.

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Participatory plant breeding as a method of rice breeding

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The total cultivated area in Jharkhand is 26 million ha; 70% of this is grown to rice. The productivity of rice in Jharkhand is 1 t ha^{-1}, which is low in comparison with the national average of 2 t ha^{-1}. The main cause of low productivity is its cultivation in the rainfed ecology, including 39% in the uplands. The government of India has released 150 varieties of rice for the rainfed uplands, but only a few became popular in farmers' fields. These varieties lack one or other traits preferred by farmers who operate in this very harsh environment. Moreover, farmers are not really involved in the breeding process. Therefore, varieties bred by the public sector are not readily accepted by rainfed upland farmers.

Considering this scenario, participatory plant breeding (PPB) may be used to develop new varieties of rice for the rainfed ecology. PPB is conducted in association with participatory varietal selection (PVS). In PVS, a survey is done to identify the most popular rice variety among the farmers and to obtain information regarding traits that determine acceptability. Once the needs of the farmers are known, the desirable parents are selected to make the crosses.

Farmers find it easier to grow a large population than to grow many entries. Therefore, a few crosses are made, but large populations are grown in advanced generations. In the crosses, one parent must come from the most adapted variety in the region for easier identification of improved progeny.

A cross was made between Kalinga III, an upland variety, and IR64, a lowland variety. Both parents were highly adapted in Jharkhand. The crosses were made in IRRI using the bulk population breeding method. The F_4 bulk was given to farmers for selection of desirable genotypes, which resulted in a rice variety named Ashoka 200F (released as Birsa Vikas Dhan [BVD] 109). Simultaneously, the F_4 bulk was grown at the BAU rice research farm and GVT farm and scientists selected Ashoka 228 (released as BVD110).

Both BVD 109 and BVD 110 were released by the Jharkhand State Seed Subcommittee in 2003 for cultivation in the rainfed uplands of the state. They yielded significantly more (by 27–28%) than Birsa Gora 102, a variety released and recommended by BAU. These varieties also had significantly higher yield (16–20%) than Kalinga III, one of the most suitable varieties in the PVS trials preferred by farmers.

BVD 109 and BVD 110 were found to be widely adapted in the target environment. Both had high mean grain yield and average regression coefficient. They also performed better than Kalinga III and Birsa Gora 102 in all aspects, especially under a poor environment (Tables 1 and 2).

Both varieties performed better in western India, although they were bred for the eastern part. A mother trial consisting of nine varieties was conducted in both irrigated and rainfed conditions in Gujarat, Rajasthan, and Madhya Pradesh. The Ashoka varieties, along with Vandana, were found to be the most drought-tolerant because of their early maturity and deeper root system. They had the smallest reduction in grain yield under drought conditions (Fig. 1). Farmers from western India gave the top rank to the Ashoka varieties for their earlier maturity, superior grain quality, better fodder yield, and higher market value. Ashoka was also preferred to Vandana, which has poor grain quality.

Table 1. Regression parameters for variety mean grain yield (t ha^{-1}) regressed on trial mean for six research trials (Jharkhand, 1999–2001) and five on-farm trials (40 farmer-replications grouped according to village clusters, Jharkhand, Orissa, and West Bengal, 1999–2001).

Variety	Overall mean (t ha^{-1})	R^2	A + SE	B + SE
Ashoka 200F	2.10	0.94	0.05 + 0.19	1.11 + 0.10
Ashoka 228	2.11	0.95	0.16 + 0.16	1.06 + 0.08
Kalinga III	1.77	0.96	0.05 + 0.12	0.94 + 0.06
BG 102	1.58	0.97	-0.29 + 0.12	1.01 + 0.06

Table 2. Mean preference ranking of selected varieties out of nine tested for trials other than grain yield in Rajasthan (1 = lowest, 9 = highest).[a]

Variety	Earlier flowering	Grain size	Test value	Cooking quality	Fodder quality	Market value	Overall ranking
Ashoka 200F	5.0	5.7	6.0*	6.0*	5.5*	6.0*	6.5*
Ashoka 228	5.0	6.0	6.0*	6.0*	5.5*	6.0*	6.0*
RR354-1	3.7	5.0	4.5	5.0	4.5	4.0	4.0
Vandana	3.7	4.7	4.5	4.0	3.5	3.5	3.5
Kalinga III	3.3	3.7	6.0	4.0	4.0	4.0	3.5
LSD 5%	2.3	1.8	1.2	1.5	1.4	1.7	1.6

[a]* = significantly better than Vandana at the 5% level.

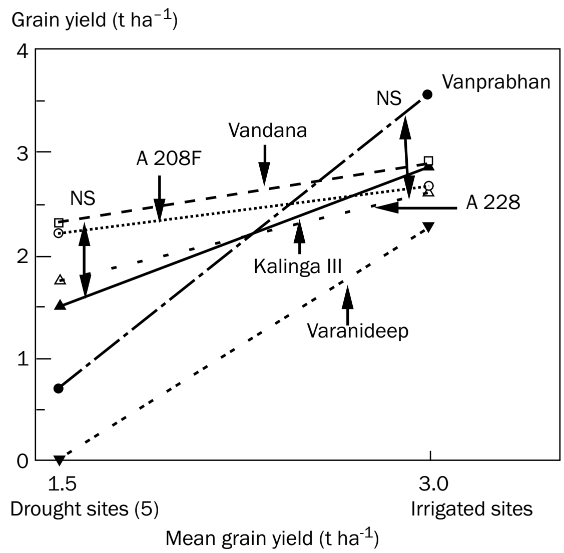

Fig. 1. Mean grain yield (t ha^{-1}) of six selected rice varieties at six irrigated and rainfed sites in Rajasthan, Gujarat, and Madhya Pradesh, 2002.

Overall, the performance of the Ashoka varieties was judged superior in terms of cooking quality, fodder yield, and price of grain in the Rajasthan market. The adoption study was also carried out in Jharkhand, Orissa, and West Bengal in December 2002 (Fig. 2). It was also observed that a majority of the farmers preferred both Ashoka varieties and wanted to grow them from the saved seed. Farmer adoption was very high in all three states. Farmers with smaller, marginal, and medium landholdings also adopted the Ashoka varieties. No relationship was found between area of adoption and total cultivable land of each farmer.

Seed production and seed dissemination through farmers' groups are advantageous from the research and extension points of view. The farmers had grown both rice varieties in participatory varietal trials, saving seeds from harvest for next-season sowing and exchanging them for seeds from other farmers and relatives. Seed production was undertaken in the off-season of 2001-02 by a farmers' group in the GVT-adapted clusters of Orissa. The farmers produced 62 t of seed of both Ashoka varieties; in the next season, 66 t of seed were produced.

The genetic gain per year from the PPB program was almost double that of conventionally bred varieties (Table 3). This has to be considered, along with gain through early maturity, because normally the enhancement of earliness is achieved at the expense of grain yield. Moreover, the varieties had given not only high grain yield but also high fodder yield.

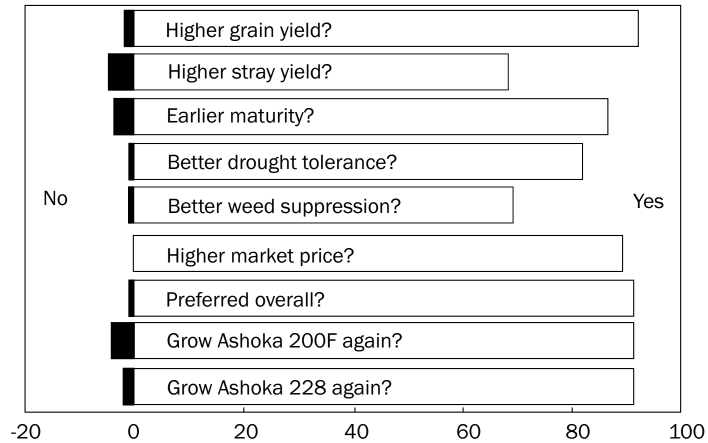

Fig. 2. Farmers' perception (% of farmers) of Ashoka varieties in comparison with local cultivars. Based on a survey in Jharkhand, Orissa, and West Bengal, December 2002.

Table 3. Comparison of genetic gains from participatory plant breeding (PPB) and conventional breeding in India.

Basis	PPB (Ashoka 200F)	Conventional breeding (BD 101)
Years from cross to completing 1 y of research trials	4	7
Years from cross to farmers	4	14
Yield gains (%) over check on research station	28% over Brown Gora 102 in six trials (1999-2001)[a]	18.5% over Brown Gora 102 in four trials (1981-84)[b]
Yield gains (%) over check in farmers' field	51% over local variety in 40 trials (2000-01)	–
Yield gains per year in		
• research station trials	7.0%	2.6%
• farmers' field trials	12.8%	–

[a]No reduction in plant height for Ashoka 200F; 5% increase in height of Ashoka 228 over Brown Gora 102.
[b]36% reduction in plant height over Brown Gora (local collection).

Genetic analysis of growth and root traits in japonica/indica cross

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Drought tolerance is a complex trait, but the crucial plant traits that control plant water status and plant production under drought have been studied extensively. Among dehydration avoidance traits, a deep, well-developed root system appears to be beneficial as it extracts water more thoroughly from the soil (Blum et al 1999). To breed efficient root systems, information on the genetics of the trait is essential. The present study was undertaken to make a genetic analysis of root architecture of a japonica/indica cross (Moroberekan/IR20), using the parents and the F_1, F_2, and F_3 generations. Roots under well-watered conditions were measured 70 d after sowing (DAS). Moroberekan, the taller parent, has a longer root system, and is more tolerant of drought than IR20, which is a high-yielding, semidwarf variety with shallow root system and high osmotic adjustment capacity. One hundred F_2 plants and 200 F_3 plants, along with the parents and the F_1, were grown in two replications in PVC pipes during 2003 kharif. Plants were screened for root characters and associated shoot traits at the peak vegetative stage. Sampling was done using the method described by Hemamalini et al (2000), with care taken to retain the roots, root hairs, and root branches. The estimates of various main effects of genes and nonallelic interaction components based on generation means were made following the perfect-fit solution as suggested by Hayman (1958).

The results suggest the presence of epistasis and a predominantly duplicate type of gene interaction. The significant positive mid-parent heterosis observed for plant height, coupled with inbreeding depression (Table 1), suggests nonadditive gene action. The number of tillers registered significant negative heterosis coupled with negative inbreeding depression, revealing the possibility of nonadditive gene action. Nonadditive gene effects seem to control leaf length, leaf width, leaf area index, and specific leaf area (Table 2). For specific leaf area, complementary epistasis between dominant decreasers was recorded, showing high negative mid-parent heterosis with negative inbreeding depression. Duplicate epistasis was observed for all other shoot traits. Shoot dry weight and total growth rate registered high mid-parent heterosis and considerable inbreeding depression in the F_3 generations, revealing the importance of nonadditive gene effects.

Root length, root volume, root dry weight, and total dry matter recorded highly significant mid-parent heterosis and negligible or low inbreeding depression, suggesting the importance of additive gene effects. These traits were influenced by additive gene effect. Hence, selection in segregating material can be made in the positive direction to increase

Table 1. Estimates of heterosis and inbreeding depression for different root and physiological traits in Moroberekan/IR20. Measurements made at 70 DAS under well-watered conditions.

Trait	Heterosis in F_2[a]	Residual heterosis in F_3	Inbreeding depression (%) $F_1 - F_2$	Inbreeding depression (%) $F_2 - F_3$
Plant height (cm)	44.36**	24.01**	-6.20**	19.11**
Tiller number	-21.80**	46.47**	-45.00**	-29.17**
Leaf length (cm)	40.08**	24.35**	-9.78*	19.13**
Leaf width (cm)	13.42**	13.42**	-6.87 ns	6.42**
Leaf area index	71.05**	146.71**	-68.08**	14.18*
Specifc leaf area ($cm^2 g^{-1}$)	-41.56**	-11.14*	-52.36**	0.09 ns
Maximum root length (cm)	43.55**	37.98**	9.41**	-6.10 ns
Root number at 15-cm depth	41.76**	104.36**	-63.10**	11.61*
Root number at 30-cm depth	61.99**	72.69**	-20.90 ns	11.82 ns
Total root number	52.13**	113.26**	-64.78**	14.92**
Root volume (cm^3)	484.10**	421.81**	1.59 ns	9.22 ns
Root dry weight (g)	177.90**	159.68**	8.03 ns	-1.60 ns
Shoot dry weight (g)	194.64**	197.86**	-16.92*	13.54**
Total dry weight (g)	188.44**	183.71**	-8.07 ns	8.98 ns
Total growth rate (cm d^{-1})	43.48**	29.02**	0.37 ns	9.73**
Specific root length (cm g^{-1})	-46.16**	-15.73*	-31.26**	-19.25ns

[a]As percentage over mid-parent value. ns = nonsignificant.

Table 2. Gene effects (Hayman 1958) in Moroberekan/IR20 for different root and physiological traits at 70 DAS under well-watered conditions in rice.

Trait	m	d	h	l	l	χ^2	Potence ratio (h/d)	Type of epistasis
PHT	117.67**	21.45**	55.38**	64.23**	-138.24**	200.87**	2.58	Duplicate epistasis between dominant increasers
NOT	7.54**	-2.85**	-7.44**	-11.29**	5.51 ns	53.86**	2.61	Duplicate epistasis between dominant decreasers
LL	56.9**	8.56**	25.66**	27.96**	-71.6**	81.37**	3.00	Duplicate epistasis between dominant increasers
LW	1.4**	0.26**	0.18**	0.56**	-0.72**	22.86**	0.69	Duplicate epistasis between dominant increasers
LAI	4.37**	-0.2*	0.48 ns	-0.99 ns	-8.03**	11.32**	-2.40	Duplicate epistasis between dominant increasers
SLA	179.13**	33.88 ns	-40.62 ns	24.78 ns	-165*	76.23**	-1.21	Complementary epistasis between dominant decreasers
MRL	69.57**	23.7**	-6.51 ns	18.08**	41.94*	48.06**	-0.27	Duplicate epistasis between dominant decreasers
RN15	63.12**	-0.8 ns	3.26 ns	-9.73 ns	-104.2**	125.53**	-4.08	Duplicate epistasis between dominant increasers
RN30	33.49**	-0.6 ns	6.68 ns	-5.11 ns	-36.53 ns	42.7**	-11.13	Duplicate epistasis between dominant increasers
RN	108.9**	-1.65 ns	14.81 ns	-11.13 ns	-200.9**	159.15**	-8.98	Duplicate epistasis between dominant increasers
RTV	56.39**	3.99**	14.46 ns	-25.04*	-25.29 ns	13.76**	3.62	Duplicate epistasis between dominant increasers
RDW	5.11**	0.7**	-0.09 ns	-2.4 ns	1.76 ns	79.77**	-0.13	Duplicate epistasis between dominant decreasers
SDW	12.85**	0.82**	3.4 ns	-2.21 ns	-14.26**	196.2**	4.15	Duplicate epistasis between dominant increasers
TDW	18.46**	1.52**	3.49 ns	-4.62 ns	-12.49 ns	188.96**	2.30	Duplicate epistasis between dominant increasers
TGR	2.67**	0.64**	0.69**	1.17**	-1.37**	115.09**	1.08	Duplicate epistasis between dominant increasers
SRL	17.08**	3.56**	-11.5**	-	-	1.43 ns	-3.23	–
R/S	0.473**	6.99**	-0.14*	0.03 ns	0.61**	9.35**	-0.02	Duplicate epistasis between dominant decreasers
RDW/T	0.88**	0.37**	0.8**	-	-	0.578 ns	2.16	–

[a] PHT = plant h ^{2} g^{-1}),
MRL = max
volume (cm^3), RDW =
length/growth period, SRL = specific root length (cm g^{-1}), R/S = root-shoot ratio, dry weight basis, RDW/TL = root dry weight /tillers (g). * = significant at 5%, ** = significant at 1%, ns = nonsignificant.

the desired trait. Root number is highly influenced by dominance/dominance gene effects, making selection in early generations ineffective.

Ekanayake et al (1985) reported a preponderance of additive gene effects in controlling root length dominance effect for root volume and root number. Sun and Zhang (1995) found both additive and nonadditive gene action controlling root number. Growth-related traits were found to be under dominance × dominance gene effects, followed by additive × additive gene interactions and dominance effects. Hence, selection should be delayed to later generations to allow fixation of sufficient epistatic interaction. Root-related traits showing a preponderance of additive effects (root length, root volume, root dry weight, and total dry matter) can be improved through selection in segregating material. In the present study, duplicate epistasis was recorded for a majority of the traits. In many of the heterotic crosses where epistasis has been investigated, duplicate epistasis rather than the complementary type has been observed (Kearsey and Pooni 1996).

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Comparative QTL mapping of root length in the Nipponbare/Kasalath and Koshihikari/Kasalath mapping populations

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Rice yields in rainfed lowland or upland environments are typically limited by a variety of abiotic stresses such as drought and nutrient deficiency or toxicity. Rice genotypes capable of developing a large root system are potentially more tolerant of these abiotic stresses because larger root systems enable them to maintain higher water or nutrient uptake rates, which can translate into superior growth and, ultimately, higher grain yield. Root growth-related traits have therefore been studied in a variety of rice populations and a large number of root growth-related quantitative trait loci (QTLs) have been identified (www.gramene.org).

One of the most widely used and publicly available mapping populations is the one derived from a Nipponbare/Kasalath//Nipponbare backcross (http://rgp.dna.affrc.go.jp/E/publicdata/genotypedataBILs/genotypedata.html). When grown in upland conditions under an imposed water deficit, Kasalath was able to produce grain yield comparable with that of tolerant upland check variety Apo (J. Cairns, IRRI, unpubl. data). Despite the apparent high drought tolerance, very few data on root growth are available for Kasalath-derived populations. The objective of this study therefore was to identify QTLs associated with root growth in the Nipponbare/Kasalath (98 RILs) and the Koshihikari/Kasalath (181 RILs) mapping populations. After germinating seeds on a mesh floating on 0.5 mM $CaCl_2$ solution for 5 d, seedlings were transferred to quarter-strength Yoshida solution containing 2.5 µM of P. Such a relatively low P concentration is similar to conditions encountered by rice plants in the field and, hence, is more suitable for detecting root elongation compared with unnaturally high P levels, which can even reduce root growth. After 7 d of growth under these conditions, root length of five seedlings in each of three replications was measured. QTL mapping was done using the software PLABQTL and a composite interval mapping algorithm.

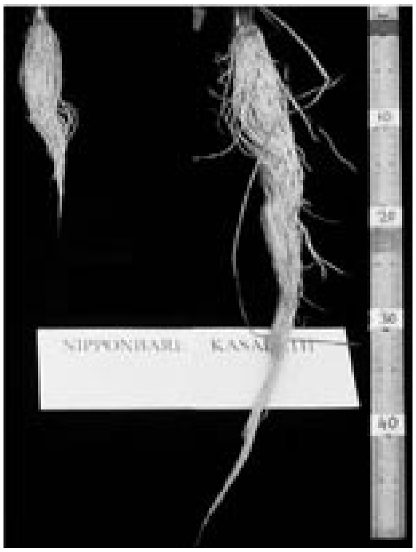
Kasalath produced significantly longer roots than Nipponbare and Koshihikari (see figure). Average root lengths on day 12 were 18.4 cm for Kasalath, 10.1 cm for Nipponbare, and 12.8 cm for Koshihikari. Absolute root length as well as genotypic differences further increased with plant age, but differences in daily root growth rates were relatively constant, suggesting that early seedling root growth is a suitable predictor of final root length in solution. Differences in seedling root growth were not due to differences in seed reserves, since seed weight and seed P content were about 20% lower in Kasalath.

In the Nipponbare-derived mapping population, three QTLs for root length were identified on chromosomes 1, 3, and 6 (see table). The QTL on chromosome 6 had a major effect, explaining 39.3% of the variation for this trait. Kasalath alleles were estimated to increase root length by 24%. In contrast, Nipponbare alleles increased root length for the minor QTL on chromosome 3. The same three QTLs with similar effects were identified in the Koshihikari-derived population. In addition, two QTLs on chro-

QTLs for seedling root length detected in either Nipponbare/Kasalath or Koshihikari/Kasalath mapping populations. (Root length measured in nutrient solution 12 d after germination.)

Chromosome	Marker interval	Position (cM)	Interval[a] (Mb)	LOD	R^2	Positive allele
			Nipponbare/Kasalath			
1	C1211- R210	53	9–11	3.5	15.2	Kasalath
3	C63-C1488	44	8–11	3.3	14.4	Nipponbare
6	R11- R1888	120	28–31	10.3	39.3	Kasalath
	Full model[b]			15.0	50.6	
			Koshihikari/Kasalath			
1	R210-C1905	50	10–13	4.3	10.6	Kasalath
2	C424-C747	94	25–28	5.8	14.0	Koshihikari
3	S10251-C1488	38	8–11	3.5	8.6	Koshihikari
6	C556-R1167	104	28–31	5.1	12.4	Kasalath
8	C502-R1963	84	25–28	3.3	8.2	Kasalath
	Full model[b]			15.8	48.1	

[a]Approximate location of the support interval on the Nipponbare sequence (version 4.0, Jan 2006). [b] Results of a multiple regression analysis that includes all main effects and digenic epistatic interactions.



Root growth of Nipponbare and Kasalath in nutrient solution after 42 d.

mosomes 2 and 8 were mapped with Koshihikari alleles having a relatively large positive effect on the QTL on chromosome 2.

The QTL locations identified here were used to search the Gramene QTL database for any co-localization with root length QTLs identified in other populations, but no hits were found. However, QTLs for root penetration had been mapped at the same locations on chromosomes 3 (Kamoshita et al 2002) and 6 (Ray et al 1996). Based on these results, we conclude that a simple screen of seedling root length in nutrient solution was able to detect the same QTLs as in more laborious evaluations for ability to penetrate compacted soil layers. That these potentially important QTLs are also detected in the Nipponbare/Kasalath population is very promising because it would be feasible to directly take advantage of the Nipponbare sequence and additional resources such as Kasalath BAC clones anchored on the sequence to study the genetic basis of root growth-related traits in this population.

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Effect of hermetic storage in the super bag on seed quality and milled rice quality of different varieties in Bac Lieu, Vietnam*

Diep Chan Ben, Bac Lieu Department of Agriculture and Rural Development; Phan Van Liem and Nguyen Tam Dao, Bac Lieu Seed Center (BLSC), Bac Lieu Province, Vietnam; and M. Gummert and J.F. Rickman, IRRI

The IRRI super bag is a farmer-friendly 50-kg storage bag that allows cereal grains to be safely stored for extended periods by using the hermetic storage principle. Hermetic storage systems rely on having the atmosphere within the grain modified through respiration of the grain, insects, and fungi. In hermetic systems, the oxygen content in the atmosphere surrounding the grains inside the grain bulk is reduced, often to less than 3%, and the carbon dioxide content increases to a level where aerobic respiration is minimized. The super bag fits as a liner bag inside a conventional storage bag and can, therefore, be used in ways similar to existing bag storage systems. The objective of this study was to determine the effect of hermetic storage in the super bag and compare it with traditional open storage in terms of quality of seed and milled rice stored for 8 mo. The experiments were conducted at the BLSC, Vietnam, using two traditional and two modern rice varieties.

Rice seeds of two traditional varieties (Tai Nguyen and Mot Bui Do) and two modern varieties (Jasmin 85 and OM2717) were stored inside the seed storage building of BLSC in super bags. The initial moisture content was between 11.3% and 13.6%. Seeds from the same lots were stored in conventional woven PVC storage bags in open storage as control. All treatments were replicated three times and the bags were placed on pallets, surrounded by metal sheets and covered with plastic to protect them from birds and rodents. Initial samples were taken at the start of the storage period in February 2005 and final

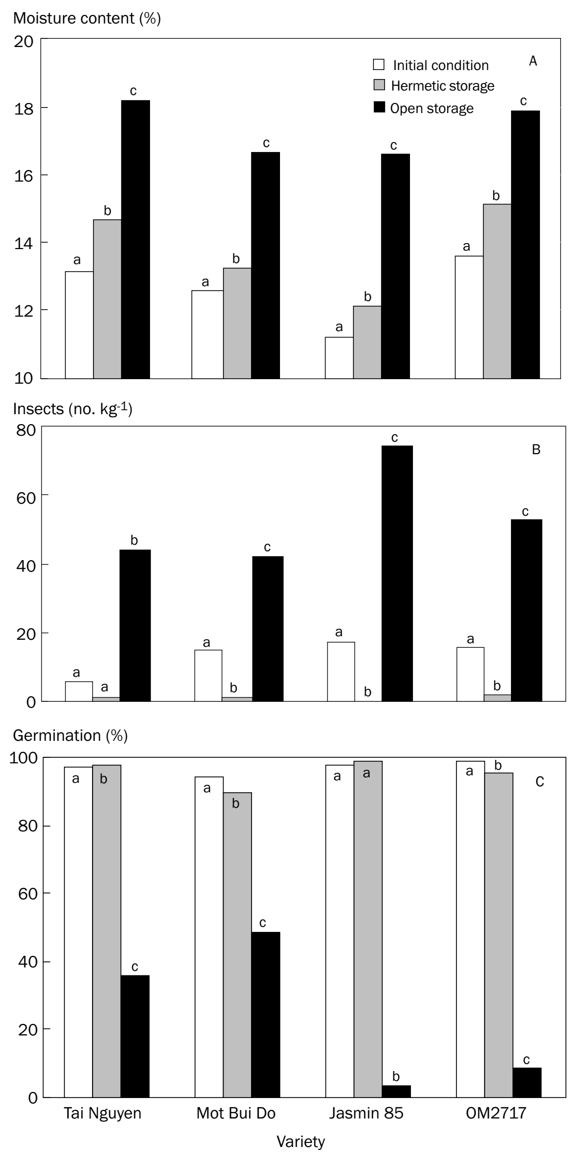

Fig. 1. Effect of 8-mo hermetic storage on A) moisture content, B) live insects, and C) germination. Within a variety, means with the same letter are not significantly different at the 5% level.

Rice as a reference genome and more

R.L. Phillips, W.E. Odland, and A.L. Kahler

The rice (*Oryza sativa* L.) genome has become the reference genome to which others are compared. Part of the reason for this is that rice has the lowest DNA content of the common cereals and its gene content and gene order are found in other grass species used for food. Having the genome sequence of rice, both japonica and indica, allows comparisons with regard to genomic structure, gene constitution, and gene expression. Map locations for single-copy genes, families of genes, and quantitative trait loci (QTLs) are often compared among species, usually with rice as the reference. Specialized databases have been developed to facilitate cross-species homology relationships relative to genome and EST sequencing, protein structure, gene function, and other useful aspects. The evolutionary relationship of rice and several other cereals such as maize (*Zea mays* L.) and sorghum is clearly observed when highlighting syntenic regions. The collinearity of rice and American wildrice (*Zizania palustris*) has been exploited to develop a molecular genetic map and to locate QTLs in wild rice. The goal of this paper is to illustrate the value of rice for comparative genome referencing.

* These abstracts are taken from papers presented at the Fifth International Rice Genetics Symposium, held in November 2005, in Manila, Philippines. To order *The Rice Genetics Collection* CD containing the proceedings of RGV, and the proceedings of the previous four Rice Genetics Symposia and other selected historic publications on the topic, go to IRRI's publication catalog at www.irri.org/publications/catalog.

samples were collected after 8 mo of storage for seed and milling quality analysis.

The super bags effectively prevented moisture exchange between the surrounding air and the grains. There was only a slight increase in moisture content of about 1.2% in the hermetic system, probably caused by respiration of the grains and insects. In contrast, the moisture content of the control treatment increased by an average of 4.7%; the final moisture content was in the 16.5–18.2% range, mainly through moisture exchange with the surrounding air (Fig. 1A), far above safe levels. The super bags also effectively reduced the number of living insects to one insect per kilogram without using pesticides. In open storage, insect levels increased to an average of 53 living insects kg^{-1} (Fig. 1B). Germination rate in the control dropped to an average of 43% for traditional varieties and 6% for the new varieties under the open-storage system, whereas hermetic storage maintained high germination rates between 90% (Mot Bui Do) and 99% (Jasmin 85) and an average germination of 96% (Fig. 1C).

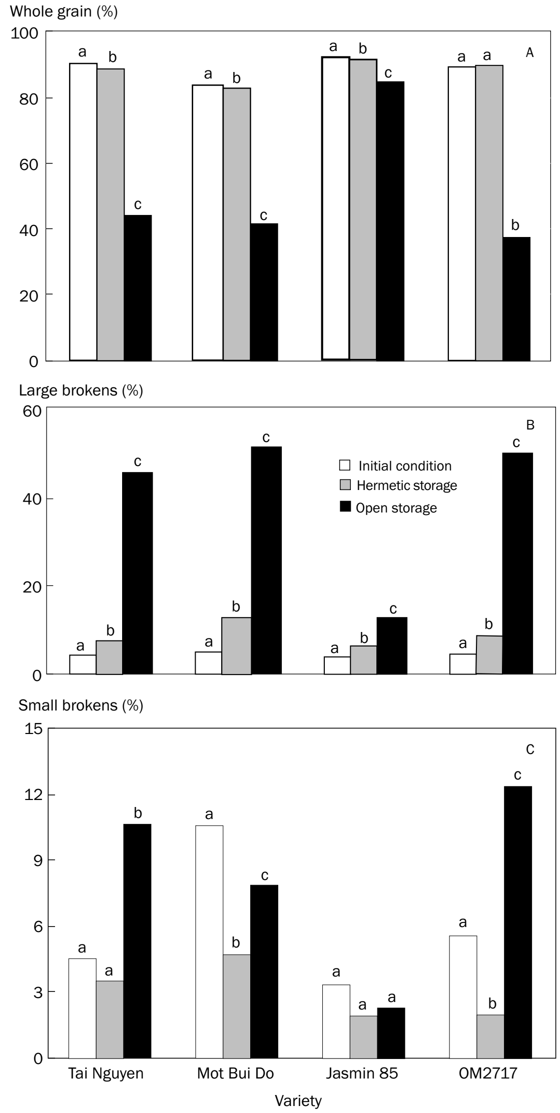

Fig. 2. Effect of 8-mo hermetic sealed storage on milling quality expressed as A) percent whole grain, B) percent large brokens, and C) percent small brokens.

After 8 mo of storage, milling recovery in open-storage samples decreased by an average of 2.9% compared with the initial sample. In hermetic storage, milling recovery was only 0.76% lower than that obtained from the initial sample. Hermetic storage thus led to a 2.14% higher milling recovery on average. The benefit of hermetic storage in terms of maintaining a high percentage of whole grains was much more obvious. In the open-storage system, whole-grain percentage decreased by 37.1 percentage points on average. In comparison, samples stored hermetically had only 1.2% less whole grain than the initial samples. Using hermetic storage, whole grain increased by an average of 35.9 percentage points compared with open storage (Fig. 2A). The grains in open storage went through repeated drying and wetting cycles when exposed to ambient air conditions, thereby resulting in an increase in both small brokens and big brokens. The results of this study showed that hermetic storage provides a simple way to retain high seed germination, obtain lower insect infestation, and maintain a high percentage of whole grain after milling.

Acknowledgment

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* Winner, 2006 IRRN Best Article Award, Agricultural Engineering

The complete rice genome sequence: a gold mine for future rice research

T. Sasaki, T. Matsumoto, J. Wu, and N. Namiki

The map-based complete rice genome sequence is now freely available to researchers worldwide, providing the most fundamental tool that should further accelerate efforts to improve the staple crop that feeds more than half the world's population. The finished-quality sequence covers 95% of the 389-Mb genome, including virtually all of the euchromatin and two complete centromeres. A total of 37,544 nontransposable-element-related protein-coding genes were identified. The complete genetic information on rice will serve as a gold mine for genomic research in rice and other cereal species. It will facilitate the identification of many important genes by both forward and reverse genetic strategies, and clarify the relationships between sequence variation and phenotypes. The genome sequence derived from *Oryza sativa* subspecies japonica can be used as a reference sequence for comparative analysis among *Oryza* species that will help in understanding the major factors involved in speciation and searching for useful genetic resources. Furthermore, the completed sequence will also serve as a standard for cereal genome comparison and identification of rice orthologous genes in other cereal crops, thereby providing a platform for establishing the genomics of each cereal species.

Annotation of the rice genome

Shu Ouyang, Wei Zhu, J. Hamilton, Haining Lin, M. Campbell, Yuandan Lee, R. L. Malek, Aihui Wang, Qiaoping Yuan, B. Haas, J. Wortman, and C. Robin Buell

A high-quality finished sequence of the rice genome was completed in 2005. However, to maximally use the sequences, quality annotation of the genes and genome features is necessary. The process of annotation is iterative in nature and requires the application and refinement of computational tools coupled with manual curation and evaluation. We are funded by the U.S. National Science Foundation to annotate the rice genome and have constructed pseudomolecules for the 12 *Oryza sativa* subspecies japonica var. Nipponbare chromosomes, which are publicly available through our project Web site (http://rice.tigr.org). We identified genes, gene models, and other annotation features in the rice genome. We expanded our annotation features to include a rice transcript assembly and its alignment with the rice genome, small noncoding RNAs, simple sequence repeats, as well as single nucleotide polymorphisms and insertions/deletions based on alignment with the indica subspecies. We updated our *Oryza* repeat database, which has allowed us to better quantify the repetitive sequences within the rice genome, which total 29% of the genome. To assist users in accessing the genome and our annotation, we

expanded the content and functions of our Rice Genome Browser such that it supports 37 annotation tracks and data downloads of the underlying annotation data in various formats.

The *Oryza* map alignment project (OMAP): a new resource for comparative genomics studies within *Oryza*

R.A. Wing, H.R. Kim, J.L. Goicoechea, Y. Yu, D. Kudrna, A. Zuccolo, S.S. Ammiraju Jetty, M. Luo, W. Nelson, C. Soderlund, P. San Miguel, N. Gill, J. Walling, S. Jackson, B. Hurwitz, D. Ware, L. Stein, D. Brar, and D. Mackill

With the completion of a finished genome sequence, we must now functionally characterize the rice genome by a variety of methods, including comparative genomic analysis between cereal species and within the genus *Oryza. Oryza* contains two cultivated and 22 wild species that represent 10 distinct genome types. The wild species, in particular, contain an essentially untapped reservoir of agriculturally important genes that must be harnessed to enhance and sustain crop productivity. OMAP was established 2 years ago to generate a comprehensive set of genomic resources to investigate genome evolution and enhance positional cloning efforts in the genus *Oryza*. To date, we have generated (1) 12 high-quality BAC libraries that encompass the 10 genome types of *Oryza*, (2) approximately 1,000 Mb of BAC end sequence from these libraries, and (3) SNaPshot fingerprint databases for 10 of the 12 libraries. All of these resources are publicly available through the AGI BAC/EST Resource Center, GenBank, or at www.OMAP.org. The fingerprints and end sequences have been combined to develop 10 phase I physical maps. Six of these physical maps, *O. nivara* (AA), *O. rufipogon* (AA), *O. glaberrima* (AA), *O. punctata* (BB), *O. officinalis* (CC), and *O. brachyantha* (FF), have been heavily manually edited (HME) and aligned to the reference rice genome sequence. These alignments have revealed a large array of genome rearrangements relative to the japonica (Nipponbare) genome and have allowed us to begin drawing a more complete picture of *Oryza* genome evolution. We present the current status of OMAP and discuss recent analysis of the HME maps and comparative sequence analysis of select loci across the *Oryza* AA genome diploids.

Analysis of oligo hybridization properties by high-resolution tiling microarrays in rice

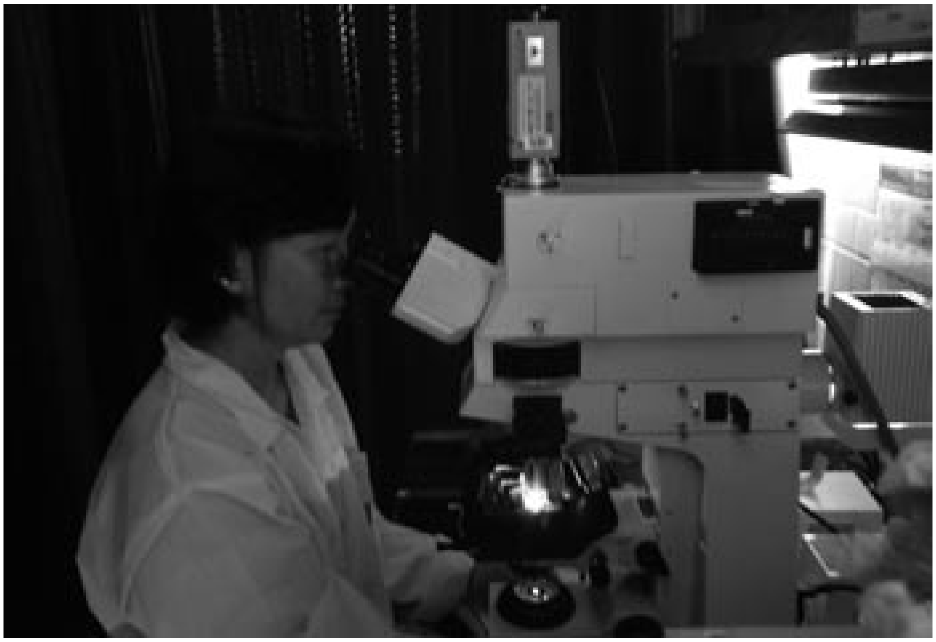
Xiangfeng Wang, Lei Li, V. Stolc, W. Tongprasit, Chen Chen, Jun Wang, Songgang Li, and Xing Wang Deng

Rice genome sequencing and computational annotation provide a static map for understanding this model of Gramineae species. With the development of in situ oligonucleotide synthesis technology, tiling-path microarrays have become a dynamic and efficient way for monitoring large-scale transcriptional activities and detecting novel transcribed elements missed by software. Unlike conventional cDNA or oligonucleotide arrays, tiling-path platforms employ the full extent of oligos covering given genomic regions, and thus offer excellent experimental conditions in which to assay the properties of oligos in terms of their specificity and efficiency of hybridization to their corresponding targets. Here, we report a tiling-path microarray analysis of a 1-Mb region (10 to 11 Mb) in japonica rice chromosome 10, which was tiled by a 36-mer oligo set at a resolution of 5 bp. Our analysis focused on three major factors of oligo hybridization properties, including GC content, melting temperature (Tm), and the repetitiveness of oligo sequences.

Tissue culture-induced mutations and overexpression of full-length cDNAs as a tool for functional analysis of rice genes

H. Hirochika, A. Miyao, M. Yamazaki, A. Takahashi, G.K. Agrawal, C. Cheng, Y. Yamashita, M. Harada, H. Nakamura, M. Hakata, and H. Ichikawa

A collection of 50,000 Tos17-induced mutant rice lines carrying about 250,000 independent insertions was generated. DNA pools derived from 50,000 lines have been produced for polymerase chain reaction (PCR)-based reverse genetic screening. For in silico screening of mutants of genes of interest, a large-scale analysis of the mutants by sequencing the genomic DNA sequence flanking Tos17 insertions is in progress. To facilitate the functional analysis, the database on phenotypes covering all the mutant lines has been developed. About half of the mutant lines exhibited at least one phenotype. About 5–10% of the mutations were shown to be caused by insertion of Tos17, whereas the rest of the mutations were deletions, possibly caused by double-strand break repair and point mutations. These deletion mutations can be detected by the PCR-based screening method, providing a new resource for functional analysis of genes. Considering gene redundancy in rice and the availability of a large number of full-length cDNAs, we have begun producing a new type of activation tagged lines in which 15,000 independent normalized full-length cDNA are overexpressed under the control of the ubiquitin promoter.



Analysis of genome sequences from the maternal and paternal parents of an elite rice hybrid

Jun Yu, Gane K.-S. Wong, Siqi Liu, Jian Wang, and Huanming Yang

We have initiated a genome project in China, the Superhybrid Rice Genome Project (SRGP), to understand the molecular basis of hybrid vigor. The early phase of the project is to sequence 93-11 and PA64S, the paternal and maternal parents of the hybrid rice strain LYP9. Preliminary analysis on genomic sequences from the parental cultivars indicates that hybrid vigor may be more complex at the molecular level than previously proposed, which is shaped, through complex and meticulous breeding practices, by intricate genetic and functional complementation processes attributable largely to variations in protein-coding sequences, regulatory elements, epigenetics, and posttranslational modifications of gene products. We are in a process of collaborating with other research groups in rice biology to acquire, in a broad spectrum, transcriptomic and proteomic data of the triad from different tissues, at multiple developmental stages and with different methods. The study should yield useful candidate genes and genetic markers for further investigations in molecular and functional details. Based on the information acquired, the SRGP initiated at the Beijing Genomics Institute will continue to map domestication-related genes and loci, based on the rich diversity of resources available in rice.

Developmental biology and gene regulation T-DNA tagging for developmental biology

G. An, D.-H. Jeong, S. An, and S. Park

We have generated 47,932 T-DNA tag lines in japonica rice using activation tagging vectors that contain tetramerized 35S enhancer sequences. To facilitate use of those lines, we isolated the genomic sequences flanking the inserted T-DNA via inverse polymerase chain reaction. For most of the lines, we performed four sets of amplifications using two different restriction enzymes toward both directions. In analyzing 41,234 lines, we obtained 27,621 flanking sequence tags (FSTs), among which 12,505 were integrated into genic regions and 15,116 into intergenic regions. Mapping of the FSTs on chromosomes revealed that T-DNA integration frequency was generally proportional to chromosome size. However, T-DNA insertions were nonuniformly distributed on each chromosome, that is, higher at the distal ends and lower in regions close to the centromeres. In addition, several regions showed extreme peaks and valleys of insertion frequency, suggesting hot and cold spots for T-DNA integration. The density of insertion events was somewhat correlated with the expressed, rather than the predicted, gene density along each chromosome. Analyses of expression patterns near the inserted enhancer showed that at least half the test lines displayed greater expression of the tagged genes. Although in most of the increased lines expression patterns after activation were similar to those in the wild type, thereby maintaining the endogenous patterns, the remaining lines showed changes in expression in the activation tagged lines. In this case, ectopic expression was most frequently observed in mature leaves. Currently, the database can be searched with the gene locus number or location on the chromosome at www.postech.ac.kr/life/pfg/risd. Upon request, seeds of the T1 or T2 plants will be provided to the scientific community.

Novel insights into the genomics of rice root adaptive development

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Deciphering the genetic and molecular mechanisms controlling the development of the root system and its adaptive plasticity under adverse environments is of primary importance for the sustainable establishment of the rice crop. Rice displays a complex root structure comprising several root types mostly of postembryonic origin. The large natural variation in root architecture among cultivars reflects their adaptation to contrasting agro-environmental conditions. This article reviews the current knowledge on the organization and anatomy of the various types of roots of the fibrous root system of rice, the diversity and genetic basis of natural variation of root system architecture and performance, and the molecular mechanisms underlying constitutive and adaptive root development. This paper also throws light on how the integrated approach of new tools in high-resolution microscopy imaging, expression profiling, mutant screening, and reverse genetics could facilitate the rapid discovery and analysis of the key genes and regulatory networks involved in root architectural traits affecting plant performance under field conditions.

Molecular signaling in disease resistance of rice

K. Shimamoto, A. Nakashima, M. Fujiwara, Nguyen Thao Phuong, L. Chen, H.L. Wong, D. Miki, K. Imai, S. Maisonneuve, H. Takahashi, Y. Kawaguchi, S. Hirai, and T. Kawasaki

Although impressive progress in the area of our understanding of molecular signaling in disease resistance of rice has been made recently, we still know relatively little about the molecular mechanisms of pathogen recognition and signal transduction leading to disease resistance. Increasing evidence indicates that Rac GTPase is an important molecular switch in disease resistance of rice. It activates the production of reactive oxygen species, defense gene expression, phytoalexin production, and lignin synthesis. Recent evidence suggests that it forms a protein complex with other factors involved in defense signaling. Two new technologies that are useful for the study of molecular signaling in defense responses in rice are discussed.

QTLs in rice breeding: examples for abiotic stresses

D.J. Mackill, B.C.Y. Collard, C.N. Neeraja, R.M. Rodriguez, S. Heuer, and A.M. Ismail

Despite the status of rice as a model agricultural crop and hundreds of studies identifying quantitative trait loci (QTLs), the applications of these results in breeding have been limited. However, the success of plant breeders in developing varieties with high yield, excellent grain quality, and wide adaptation that are widely grown by farmers (i.e., mega varieties) has provided an opportunity to deploy the most useful QTLs for rice improvement. Marker-assisted backcrossing (MAB) facilitates the precise introgression of a desired trait into the original genetic background of such mega varieties. QTLs with a large effect are rare for complex agronomic traits like yield but are more common for other traits such as resistance to abiotic stresses. Here we discuss the example of submergence tolerance. Much of the tolerance in varieties such as FR13A has been shown to be under the control of the *Sub1* locus, which includes 2–3 tightly-linked putative transcription factors. *Sub1* was transferred into the Indian cultivar Swarna, resulting in a new version of this mega variety with tolerance for submergence. Large QTLs also exist for tolerance for salinity, P deficiency, Al toxicity, and low temperature. With some modifications, this approach may be applicable for traits controlled by multiple smaller QTLs. However, strategies for transferring multiple QTLs into mega varieties need to be developed such that negative effects of the transferred segments (linkage drag) do not adversely affect the resulting varieties. Furthermore, strategies for reducing the costs associated with marker genotyping and efficient phenotyping also need to be developed and adopted in order to apply MAB on a larger scale.

Isolation of a QTL gene controlling grain number and QTL pyramiding to combine loci for grain number and plant height in rice

M. Ashikari, S. Lin, T. Yamamoto, T. Takashi, A. Nishimura, E.R. Angeles, Q. Qian, H. Kitano, and M. Matsuoka

Many agronomically important traits, including yield, are expressed in continuous phenotypic variation. These complex traits usually are governed by a number of genes known as quantitative trait loci (QTLs) derived from natural variations. Now, QTL analysis has been employed as a powerful approach to discover agronomically useful genes. Grain number and plant height are important traits that directly contribute to grain productivity. We aimed to identify genes of QTLs for grain number and plant height, not only to elucidate molecular mechanisms that regulate grain productivity but also to use these genes for breeding. We first identified that a QTL that increases grain productivity in rice, *Gn1a*, is a gene for cytokinin oxidase/dehydrogenase (OsCKX2), an enzyme that degrades the phytohormone cytokinin. Reduced expression of OsCKX2 causes cytokinin accumulation in inflorescence meristems and increases the number of reproductive organs, resulting in enhanced grain yield. QTL pyramiding to combine loci for grain number and plant height in the same genetic background generated lines exhibiting both beneficial traits. These results provide a strategy for tailor-made crop improvement. Discovering useful genes, improving agricultural traits hidden in the plant genome, and applying these findings to crop breeding will pave the way for a new green revolution.

Genetic and molecular dissection of flowering time in rice

M. Yano and T. Izawa

Flowering time (heading date) is a major determinant of regional and seasonal adaptation of cultivated rice. A large amount of variation is observed in heading date and photoperiodic response among rice cultivars and strains, including wild relatives. Quantitative trait locus (QTL) analyses of progeny derived from several cross combinations of rice cultivars suggest that more than 15 loci are involved in heading date. Map-based cloning has been performed on several QTLs for photoperiodic response. We have demonstrated that Heading date 1 (*Hd1*) is an ortholog of CONSTANS (CO) in *Arabidopsis* and is involved in the promotion of heading under short-day (SD) conditions and inhibition under long-day (LD) conditions. *Hd6* is involved in inhibition under LD conditions and encodes the alpha-subunit of protein kinase CK2. *Hd3a* shows a high level of similarity to *Arabidopsis* FT (flowering time) and functions as a flowering inducer. Early heading date 1 (*Ehd1*) is involved in promotion under SD conditions and encodes a B-type response regulator.

Hd5 is involved in inhibition under LD conditions and encodes a putative subunit of a CCAAT-box-binding protein. Late heading date 4 (*Lhd4*) is involved in inhibition under LD conditions and encodes a protein with a CCT motif. The combining of information from genetic and sequencing analyses reveals that the combination of natural alleles with loss or gain of function at particular QTLs, such as *Hd1, Hd5, Hd6, Ehd1*, and *Lhd4*, seems to generate a wide range of continuous variation in photoperiodic flowering in rice. These genetic and molecular analyses have allowed us to propose a pathway for the genetic control of photoperiodic flowering in rice, and analysis of the mRNA levels of genes in near-isogenic lines has clearly revealed their hierarchical relationship in the genetic control pathway. Identification and expression analyses of genes suggest the conservation and divergence of various features in the photoperiodic control of flowering in rice, an SD plant, and *Arabidopsis*, an LD plant.

Understanding broad-spectrum durable resistance in rice

J.E. Leach, R. Davidson, B. Liu, P. Manosalva, R. Mauleon, G. Carrillo, M. Bruce, J. Stephens, M.G. Diaz, R. Nelson, C. Vera Cruz, and H. Leung

A long-standing goal in rice disease control is to identify and incorporate broad-spectrum durable resistance (BSDR). Although quantitative resistance can potentially contribute to BSDR, neither the genes responsible for quantitative resistance nor the pathways or mechanisms by which they may function to contribute to BSDR are understood. Using varieties that show durable resistance historically, we have identified rice genes that are candidates for contributing to BSDR through co-localization with disease resistance QTLs in mapping studies. Several of these genes are known as disease defense response genes (e.g., *oxalate oxidase*, *chitinase*, *PR1*, etc.), whereas others are of unknown function. Genome-wide expression analyses at critical stages of host-pathogen interactions are also being used to reveal additional genes that may play a role in quantitative resistance. By combining chromosomal segments associated with five different candidate genes by marker-assisted selection, rice lines were produced that exhibited a high level of resistance to rice blast in multilocation trials. The current challenge is to understand if and how these candidate genes contribute to BSDR as well as the allelic variation that accounts for function in some lines but not in others. Targeted gene expression and functional analyses of candidate gene family members, for example, the *oxalate oxidase* gene families, are being used to focus on gene members involved in BSDR, and to determine what gene structural features are key to involvement. Sequence comparisons are providing clues as to critical allelic variation in rice germplasm. Finally, analysis of mutants exhibiting inappropriate activation of defense pathways is guiding the selection of candidate genes or genic regions. The integration of expression, mapping, and allelic diversity data is expected to unveil genes or gene interactions with significant phenotypic effects that can be used in breeding programs.

Discovery and transfer of trait-enhancing alleles from wild species

S.R. McCouch, M. Sweeney, J. Li, H. Jiang, M. Thomson, E. Septiningsih, P. Moncada, J. Xiao, J. Coburn, E. Fraker, A. Garris, T. Tai, C. Martínez, J. Tohme, M. Sugiono, A. McClung, L.P. Yuan, and S.-N. Ahn

The approach demonstrated by this collaborative breeding project has had important implications for the use of exotic germplasm in wide crosses of rice. We demonstrated that AB-QTL analysis is capable of (1) successfully uncovering positive alleles that were not obvious based on the phenotype of the parent, (2) offering an estimation of the value of crosses between O. *sativa* and exotic or genetically distant germplasm, and (3) identifying molecular markers for numerous alleles of interest to aid in their incorporation into elite cultivars with a minimum of linkage drag. The project explored the distribution of diversity within and between subpopulations of rice, building on the unique evolutionary history of the species to explore the genetic architecture and combining ability of groups within and between species. The long-term potential of exploiting the well-partitioned gene space in rice depends on appropriate management of these gene pools and a sound intellectual framework within which the genetic variation of *Oryza* is explored and manipulated. It is of great interest to integrate knowledge about the evolution and natural population structure of this and other domesticated species to better manage and exploit natural variation for crop improvement.

Genomics-based strategies for the development of "green super rice"

Qifa Zhang

Several challenges need to be met for sustainable rice production in China and to reduce the gap between potential yield and yield under large-scale production: (1) the increasingly severe occurrence of insects and diseases and the indiscriminate application of pesticides, (2) high pressure for a yield increase and overuse of fertilizers, and (3) the increasingly frequent occurrence of drought, resulting in water shortage. We have been using a combination of approaches based on recent advances in genomics research to address these challenges, with the long-term goal of developing rice cultivars referred to as "green super rice." To obtain a yield increase and improve quality, green super rice should possess resistance to multiple insects and diseases, high nutrient efficiency and drought tolerance, and potential to greatly reduce the use of pesticides, chemical fertilizers, and water. Most current efforts have focused on identifying germplasm and discovering genes for improving rice cultivars for the following traits: resistance to diseases and insects, N and P efficiency, and drought tolerance. Approaches adopted include (1) screening of germplasm collections, (2) mapping and identifying QTLs, (3) screening of mutant libraries, (4) microarray analysis of genes differentially regulated, and (5) functional tests of candidate genes by transgenic analysis. Progress toward the development of "green super rice" currently made in our group is presented.

From gene to adaptation in rice

K. Onishi and Y. Sano

The recent accumulation of information on plant genomes has enabled us to study adaptive traits at both the phenotypic and molecular levels. Genetic diversification is a consequence of the existence of a diverse set of environments. Plant breeding will accelerate the rate of micro-evolution in our changing world. To understand ongoing micro-evolutionary processes, genetic alterations in response to temperature, photoperiod, and biotic environments were investigated in wild and cultivated rice. These adaptive mechanisms were not well explained by a few major genes, suggesting that epistasis, genoype × environment interaction, and linked genes were involved in addition to genes with a small additive effect. Genetic diversity is affected both by current patterns of micro-evolutionary forces, such as gene flow and selection, and by phylogenetic history. Genealogies of agronomic genes provided insight into their history. Unexpectedly, the "Green Revolution" gene (*sd1*) preexisted in the wild ancestor, showing that farmers selected it to obtain a high yield in response to altered practices

in agriculture. In contrast, in the case of *C*, *A*, and *wx* genes, variants were generated from landraces through natural or artificial selection, suggesting that each of the genes may have its own history.

Lessons from applying genomics to wheat and barley improvement

P. Langridge

On the surface, wheat and barley have little to offer the rice genomics research community. They have very large genomes without a physical map, making positional cloning complex, and they are difficult to transform, which hinders the functional analysis of genes and delivery of transgenic technologies. However, shifts in plant genomics research into understanding the basis of diversity and mechanisms involved in creating and maintaining genome complexity have shifted research from a model organism toward more complex species. Wheat and barley are becoming increasingly attractive organisms for many of the new genomics studies. Several key tools have been important for this change, including detailed and well-phenotyped populations, mapping of a large collection of ESTs, and studies of synteny with rice and maize. Importantly, wheat and barley are widely adapted and there has been extensive monitoring and archiving of genotypes and associated phenotypic data. We also have populations adapted to specific environments and end-uses that have resulted from a long history of selective breeding. These advantages are becoming increasingly significant as analytical tools improve. Early genomic efforts in wheat and barley have delivered useful markers for application in breeding programs and identified key regions of the genome that carry disease-resistance loci, tolerance for abiotic stresses, and components of quality. The expanding resource base for wheat and barley genomics and the new insights being gained into genome organization and behavior of these species offer improvements in our ability to identify new sources of variation and to implement this information in breeding programs.

The major chromosome pairing locus (*Ph1*) in hexaploid wheat: a prospective

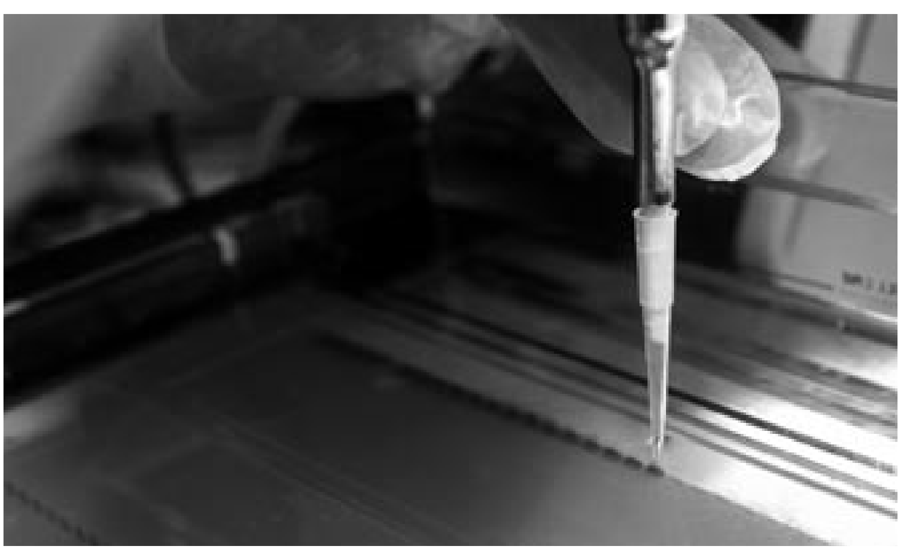
G. Moore

Western civilization owes much of its foundation to pasta and bread wheat. These species are polyploidy, possessing multiple diploid sets of chromosomes. Pasta and bread wheats exist only because the *Ph1* locus stabilizes the pairing of these multiple related chromosomes at meiosis. It provides a high level of fertility and seed set. This article reviews current knowledge of the biological effect of this important locus. It provides insights into how one might induce pairing between related chromosomes for breeding.

Functional genomics for gene discovery in abiotic stress response and tolerance

K. Shinozaki and K. Yamaguchi-Shinozaki

Plants respond to abiotic stresses, such as drought, high salinity, and cold, to acquire stress tolerance. Molecular and genomic studies have shown that a number of genes with various functions are induced by abiotic stresses, and that various transcription factors are involved in the regulation of stress-inducible genes in *Arabidopsis* and rice. These gene products function not only in stress tolerance but also in stress response. In this review, recent progress in the analysis of complex cascades of gene expression in drought and cold stress responses is summarized. Various genes involved in stress tolerance are also discussed for their application to molecular breeding of drought, salinity, and/or cold stress tolerance.



Expression and functional analysis of rice genes involved in reproductive development and stress response

A.K. Tyagi, J.P. Khurana, P. Khurana, S. Kapoor, V.P. Singh, A.K. Singh, J.K. Thakur, V. Gupta, S. Anand, S. Vij, M. Jain, S. Ray, P. Agarwal, R. Arora, P. Sharma, S. Mukherjee, A. Nijhawan, J. Giri, and R. Khurana

The rice genome sequenced and annotated by the IRGSP has identified 37,544 protein-coding genes. In an effort to identify genes encoding transcription factors and signal transduction components, more than 7,000 genes belonging to 87 classes have been used to prepare a local database. Detailed analysis of genes for plant hormone response, CDPKs, C2H2 zinc-finger, and SET domain proteins unraveled interesting evolutionary aspects in relation to genes and the rice genome. A 51k microarray, SAGE analysis, and real-time polymerase chain reaction revealed differential expression of target genes during reproductive development and stress conditions. Several genes specific to reproductive floral organs and seed development have been identified. A large number of SAGE tags are observed from intergenic regions and antisense strands reflecting the unexplored transcription potential of the rice genome. Analysis of rice gene promoter activities has been undertaken in transgenic tobacco/*Arabidopsis* to demarcate regions conferring anther-pollen-specific expression. *OSISAP1*, a gene coding for a stress-associated zinc-finger protein, and its promoter have been functionally validated in transgenic tobacco and rice. Genes for proteins interacting with *OSISAP1* have also been found to be stress-inducible. Investigations on functional analysis of stress-responsive genes are in progress.

Designing and constructing novel gene promoters to generate stress-tolerant plants without yield penalty

Tuan-hua David Ho, Chwan-Yang Hong, Ming-Tsair Chan, and Sumay Yu

Although genetic engineering has become an important practice in agricultural biotechnology, how to properly control the expression of transgenes in transgenic plants remains a challenging task. Strong constitutive promoters are routinely used in plant transformation, but sometimes their use leads to undesirable secondary effects and negatively affects the overall performance of transgenic plants. In order to maximize the benefits of transgenes and to avoid unexpected negative impact, tissue-specific stress-/ABA-inducible promoters have been designed and constructed based on knowledge learned from studies of native promoters. Microarray analysis and bioinformatics are also employed

in an extensive search for stress-/ABA-inducible and tissue-specific promoters, and information obtained is used to broaden the foundation for constructing synthetic designer promoters. The efforts include (1) optimization of upstream ABA- /stress-responsive *cis*-acting elements such as AB responsive element (ABRE) and coupling element (CE), (2) a search for the most efficient minimal promoter and desirable introns, and (3) the addition of tissue-specific determinants. Various versions of synthetic stress-/ABA-inducible promoters have been constructed, and some of them have been tested in transgenic plants for the expression of beneficial genes in conferring stress tolerance. Although transgenic plants with either a strong constitutive promoter or synthetic stress inducible promoter acquire an elevated level of stress tolerance, only the latter display normal growth and development without any apparent yield penalty under normal conditions.

Rice: an emerging model for plant system biology

A. von Zychlinski, S. Baginsky, and W. Gruissem

Proteomics has become a powerful technique to investigate cellular processes and network functions. This became possible as a result of major progress in the sensitivity of mass spectrometry instrumentation and data analysis software. As proteomics technologies are now becoming available to the wider scientific community, efforts are under way to identify complete proteomes. This information is used to improve genome annotation and to identify and confirm protein splice variants. Analysis of protein modifications and protein variants uses novel scoring and prediction tools independent of established protein databases. We discuss the proteomics tools and analysis pipelines that can be applied to rice in order to facilitate our understanding of rice genome structure and function.

IRRN welcomes three types of submitted manuscripts: research notes, mini reviews, and "notes from the field." All manuscripts must have international or pan-national relevance to rice science or production, be written in English, and be an original work of the author(s), and must not have been previously published elsewhere. By submitting the manuscript, the author automatically assigns the copyright of the article to IRRI.

Research notes

Research notes submitted to IRRN should

- report on work conducted during the immediate past 3 yr or work in progress
- advance rice knowledge
- use appropriate research design and data collection methodology
- report pertinent, adequate data
- apply appropriate statistical analysis, and
- reach supportable conclusions.

Routine research. Reports of screening trials of varieties, fertilizer, cropping methods, and other routine observations using standard methodologies to establish local recommendations are not ordinarily accepted.

Preliminary research findings. To reach well-supported conclusions, field trials should be repeated across more than one season, in multiple seasons, or in more than one location as appropriate. Preliminary research findings from a single season or location may be accepted for publication in IRRN if the findings are of exceptional interest.

Preliminary data published in IRRN may later be published as part of a more extensive study in another peer-reviewed publication, if the original IRRN article is cited. However, a note submitted to IRRN should not consist solely of data that have been extracted from a larger publication that has already been or will soon be published elsewhere.

Multiple submissions. Normally, only one report for a single experiment will be accepted. Two or more items about the same work submitted at the same time will be returned for merging. Submitting at different times multiple notes from the same experiment is highly inappropriate. Detection will result in the rejection of all submissions on that research.

Manuscript preparation. Arrange the note as a brief statement of research objectives, a short description of project design, and a succinct discussion of results. Relate results to the objectives. Do not include abstracts. Up to five references may be cited. A list of 3-5 key words should be supplied. Restrain acknowledgments. Limit each note to no more than two pages of double-spaced type-written text (approximately 500 words).

Each note may include up to two tables and/or figures (graphs, illustrations, or photos). Refer to all tables and figures in the text. Group tables and figures at the end of the note, each on a separate page. Tables and figures must have clear titles that adequately explain contents.

Apply these rules, as appropriate, to all research notes:

Methodology

- Include an internationally known check or control treatment in all experiments.
- Report grain yield at 14% moisture content.
- Quantify survey data, such as infection percentage, degree of severity, and sampling base.
- When evaluating susceptibility, resistance, and tolerance, report the actual quantification of damage due to stress, which was used to assess level or incidence. Specify the measurements used.
- Provide the genetic background for new varieties or breeding lines.
- Specify the rice production systems as irrigated, rainfed lowland, upland, and flood-prone (deepwater and tidal wetlands).
- Indicate the type of rice culture (transplanted, wet seeded, dryseeded).

Terminology

- If local terms for seasons are used, define them by characteristic weather (dry season, wet season, monsoon) and by months.
- Use standard, internationally recognized terms to describe rice plant parts, growth stages, and management practices. Do not use local names.
- Provide scientific names for diseases, insects, weeds, and crop plants. Do not use local names alone.
- Do not use local monetary units. Express all economic data in terms of the US$, and include the exchange rate used.
- Use generic names, not trade names, for all chemicals.
- Use the International System of Units for all measurements. For example, express yield data in metric tons per hectare (t ha^{-1}) for field studies. Do not use local units of measure.
- When using acronyms or abbreviations, write the name in full on first mention, followed by the acronym or abbreviation in parentheses. Use the abbreviation thereafter.
- Define any nonstandard abbreviation or symbol used in tables or figures in a footnote, caption, or legend.

Mini reviews

Mini reviews should address topics of current interest to a broad selection of rice researchers, and highlight new developments that are shaping current work in the field. Authors should contact the appropriate editorial board member before submitting a mini review to verify that the subject is appropriate and that no similar reviews are already in preparation. (A list of the editors and their areas of responsibility appears on the inside front cover of each IRRN issue.) Because only 1-2 mini reviews can be published per issue, IRRN will require high quality standards for manuscripts accepted for publication. The reviews should be 2000-3000 words long, including references. Refer to the guidelines for research notes for other aspects of writing and content.

Notes from the field

Notes from the field should address important new observations or trends in rice-growing areas, such as pest outbreaks or new pest introductions, or the adoption or spread of new crop management practices. These observations, while not the result of experiments, must be carefully described and documented. Notes should be approximately 250 words in length. Refer to the guidelines for research notes for other aspects of writing and content.

Review of manuscripts

The IRRN managing editor will send an acknowledgment card or an email message when a note is received. An IRRI scientist, selected by the editorial board, reviews each note. Depending on the reviewer's report, a note will be accepted for publication, rejected, or returned to the author(s) for revision.

Submission of manuscripts

Submit the original manuscript and a duplicate, each with a clear copy of all tables and figures, to IRRN. Retain a copy of the note and of all tables and figures.

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Global advances in the ecology and management of golden apple snails (edited by R.C. Joshi and L.S. Sebastian; published by the Philippine Rice Research Institute; 600 pages; developed countries US$102, developing countries $52).

Golden apple snails are one of agriculture's worst invasive alien species. This new publication compiles all available information on this devastating pest and the rice systems and countries it has afflicted. The book fills a vacuum on the ecology and management of golden apple snails at a time when their distribution continues to expand.

Topics covered include snail taxonomy, impacts on aquatic ecosystems and farmers' health, and pesticide misuse. Countries suffering golden apple snail invasions have submitted individual reports. There are also chapters dedicated to the use of golden apple snails as a food and as a natural paddy weeder.

Practical in its scope, the book offers ecological and sustainable ways to deal with golden apple snail invasions. This publication will serve as a manual for field researchers and extension workers, and as a reference textbook for biological science students, industry workers, museums, and libraries.

To purchase, visit www.philrice.gov.ph or contact Chona Suner-Narvadez at csnarvadez@philrice.gov.ph or PhilRice, Maligaya, Muñoz Science City, 3119 Nueva Ecija, Philippines.

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Rice has long been the most important food crop cultivated in Laos. This book helps document the long association of Laos and its people with rice in historical, cultural, and agricultural contexts and provides a summary of some of the more salient recent advances in rice-related research undertaken since 1990. It is the result of a collaborative effort among international scientists and scholars, and researchers within Laos, with the support of the Australian Centre for International Agricultural Research (ACIAR) and IRRI.

Edited by J.M. Schiller, M.B. Chanphengxay, B. Linquist, and S. Appa Rao

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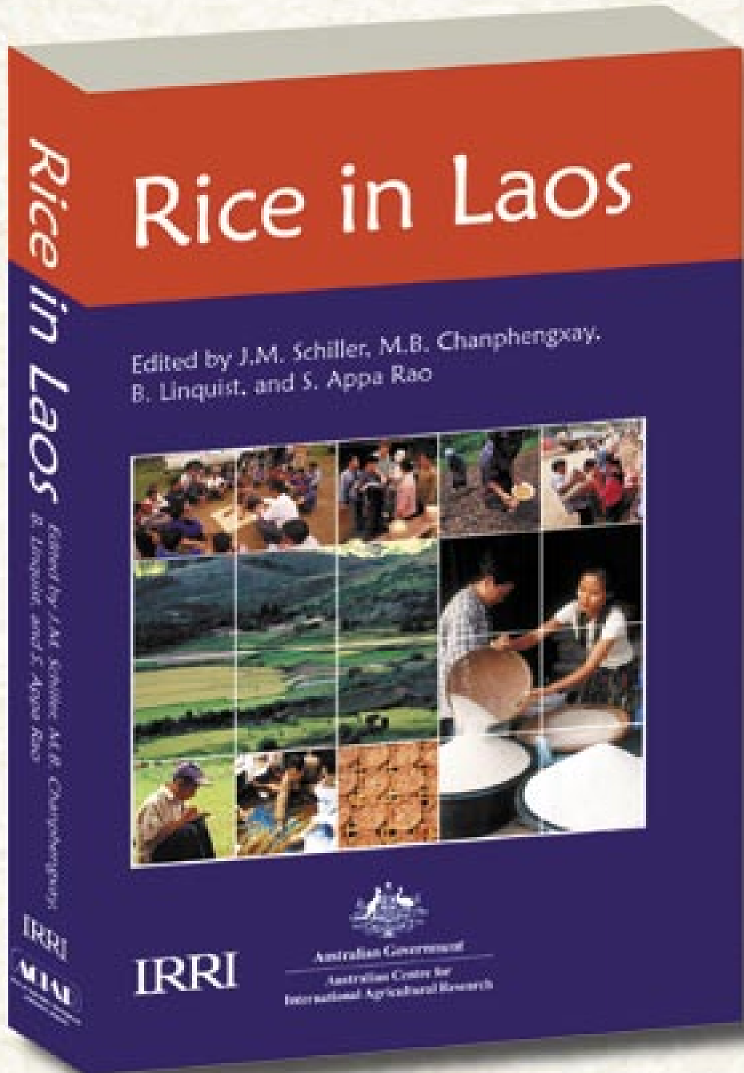

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